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THE U. S. NAVY
ELECTRONICS
LABORATORY'S

OCEANOGRAPHIC
RESEARCH
TOWER

Its Development and Utilization

EL / REPORT 1342

RESEARCH AND
DEVELOPMENT REPORT

22 DECEMBER 1965

E. G. LaFond

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OCEANOGRAPHIC
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OF THIS
LIMITED

AND

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THE PROBLEM

Develop an oceanographic research tower and evaluate its use for studying the shallow water oceanographic environment.

RESULTS

1. The Navy Electronics Laboratory (NEL) has constructed a unique oceanographic research tower for the study of a broad range of marine environmental problems.
2. The tower is readily accessible from NEL. It provides laboratory-like conditions (stability, quietness, extensive instrumentation) for shallow water research in the open sea. It is adapted to a wide diversity of studies. It is also more economical to operate than a ship anchored in the same location.
3. The tower is being successfully used to study water motion, underwater acoustics, electromagnetic propagation, marine chemistry, marine biology, and marine geology. It also serves to test and evaluate newly developed techniques and equipment, and to furnish assistance to other Navy laboratories working on oceanographic problems.

RECOMMENDATIONS

1. Expand facilities on the NEL Oceanographic Research Tower to meet the need for a larger work area.
2. Initiate new research, including investigations with radar, infrared, laser, and at the air-sea interface.
3. Build a new similar tower west of the present one in water 100 feet deep. This deeper tower will:
 - (a) Permit study of water-structure features at greater depths and allow for investigating the seasonal thermocline for longer periods of time.
 - (b) Facilitate joint research projects with ships, submarines, and other submersible vehicles requiring deep water.
 - (c) Serve as a second platform for intertower acoustic studies.

ADMINISTRATIVE INFORMATION

Work was performed under Problem L40461, SR 004 04 01, Task 0580 by members of the Marine Environment Division. This report covers the period June 1955 through December 1965.

Acknowledgment is made to a large number of devoted engineers and scientists who have made the tower a great success. The original structure and instrumentation were formulated mainly by A. L. Nelson and W. H. Armstrong. Special contributions to the installation and equipment were made by L. C. Thompson, D. A. Baldwin, W. C. McSparron, J. M. Prince, R. F. Kimball and J. V. Pflaum.

Since 1962, D. E. Good has assumed responsibility for the tower and has expanded equipments and facilities. He has been assisted by P. A. Hanson, D. L. Jackson and K. E. Titland. Able assistance is also acknowledged of marine services personnel, including H. G. Kiner, G. B. Ryan, L. L. Jones, H. E. Sprekelmeyer, A. M. Huehn, and C. T. Bell. The scientific divers J. A. Beagles, J. R. Houchen, and W. J. Bunton have been most helpful for underwater installations and repairs, and have developed new equipments and techniques for underwater operations.

The NEL Operations Officer and the personnel boat crew have provided transportation to the tower.

A large part of the research reported here was the work of the following scientists: J. R. Olson, P. G. Hansen, E. G. Barham, R. F. Dill, J. C. Thompson, R. K. Logan, F. Watenpugh, H. L. Heibeck, D. G. Moore, N. Malley, T. Abe (Tokyo, Japan), H. De Lauze (Marseilles, France), and J. Armstrong (Plymouth, England). The work of these and many others is listed in the Bibliography at the end of this report.

I am also indebted to G. H. Curl, O. S. Lee, D. E. Good, E. G. Barham, A. L. Nelson, and K. G. LaFond for reviewing this report.

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INTRODUCTION

The need for research in oceanography is expanding more rapidly than can be accommodated with present laboratory and floating facilities. To meet this demand many new types of installations are being developed. One example is the U.S. Navy Electronics Laboratory Oceanographic Research Tower, located in 60 feet of water off Mission Beach, San Diego, California. This tower is the first stationary sea-based-facility designed and used exclusively for investigating a wide variety of shallow marine environmental features.

Knowledge of the physical, chemical, biological, and geological characteristics of the shallow-water zone is essential to the Navy for the development of improved methods of underwater detection, navigation, and communications.

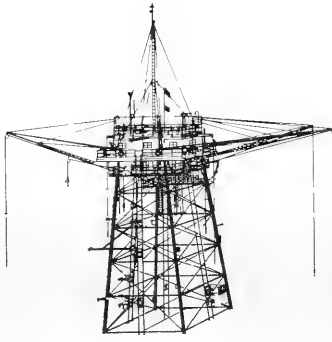
After 6 years of operation, an analysis of the oceanographic data collected has demonstrated the tower's capability in fulfilling its assigned mission. Much of the information has been reported in scientific and technical publications. Other material has been published in appropriate laboratory reports and memorandums.

Part I of this report outlines the tower's principal advantages over other methods for conducting intensive shallow marine research.

Part II briefly describes selected tower studies. The space given to each study does not reflect its relative importance or the effort expended. Instead, the treatment illustrates the diversity of investigations, the specialized techniques and instrumentation employed, and the results achieved. More detailed information on particular studies may be found in the reports and papers listed in the Bibliography (page 149).

Part III traces the tower's development from idea through construction and modifications to the present. In addition, it surveys level-by-level the unique facilities that have contributed to the overall success of the research program.

Part IV delineates the need for a new oceanographic tower to conduct studies at a greater depth (100 feet) and in an acoustic range between the present and new towers. This section also summarizes results of the oceanographic tower program and presents specific recommendations for improvement.



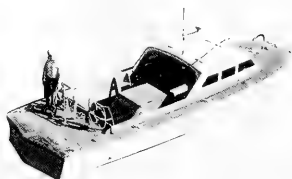
PART I.

The oceanographic research tower possesses a number of important advantages and a few limitations over the more conventional method of investigating a shallow marine environment with an anchored ship.

The main limitation of the tower is that it is not mobile. It is restricted to shallow-water studies at its fixed location, and it is not suitable for geographic oceanography. To obtain additional area coverage, it is necessary to use booms or to anchor sensors away from the structure.

ACCESSIBILITY

The tower is about a mile from shore and is within easy commuting distance of the Navy Electronics Laboratory. It is also accessible by radio. A 140.43 Mc/s communications network links the tower with the NEL communications office, the oceanographic division office, and all small assigned boats. The network can also be connected with other frequencies used by the Laboratory's larger oceanographic vessels.



Personnel, laboratory equipment, and operating supplies travel conveniently between dock and tower on a 34-foot Navy personnel boat (LCPL). This boat makes four scheduled trips a day. It is also available for operations around the tower between trips, and at off hours. Equipment is also transported by the boat and brought aboard by means of boom and nylon webbed basket.



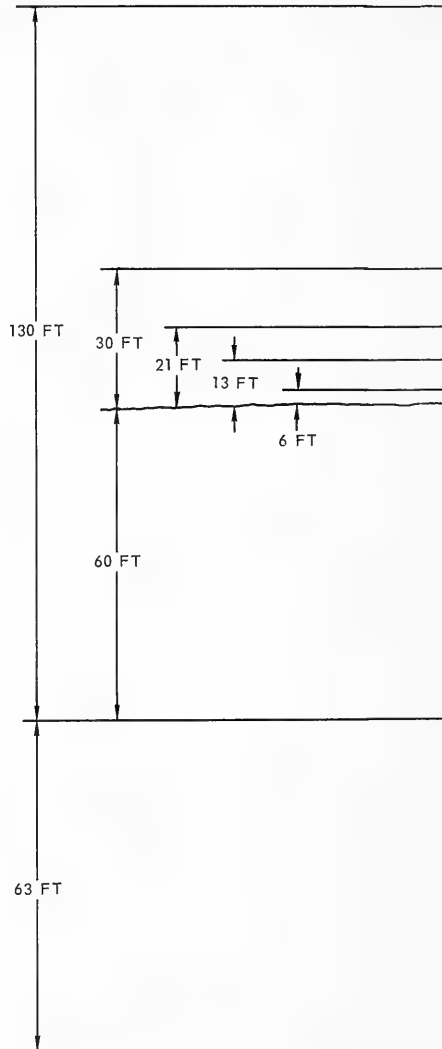
The tower is only 30 minutes from NEL — 15 minutes by car to the dock facilities at Quivira Basin, Mission Bay, and another 15 minutes by boat to the tower. Yet it is far enough from shore and populated areas to provide a natural undisturbed open-sea environment. Because it is outside lanes of heavy commercial ship traffic, the tower presents a minimum navigational hazard.

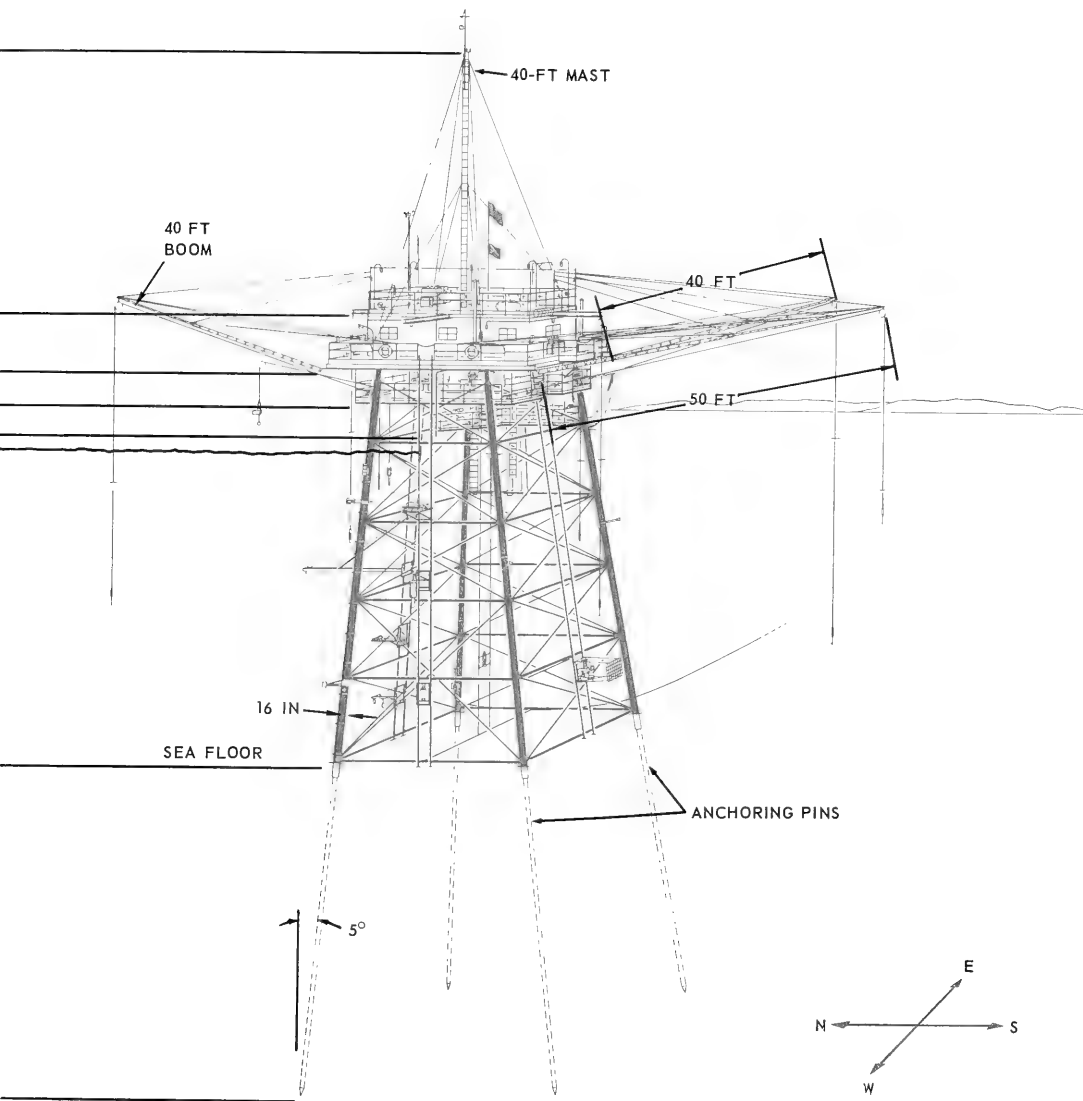
STABILITY

Another asset of the tower is its stability (and high safety factor) under strong winds, waves, and current. It has withstood storm waves up to 18 feet high.

The main reason for the tower's steadiness (and the way it differs from practically all other offshore towers) lies in the positioning of the legs. Instead of being perpendicular to the bottom, the legs slant out from the tower platform at a 5-degree angle from the vertical, forming a broad base on the sea floor. In addition, the tower is structurally rigid, and is firmly anchored to the sea floor by 12.75-inch steel pins driven a distance of 63 feet through the bottom sediment to the hard substrata.

Since the tower does not move, it provides a fixed reference point for all types of water motion studies (waves, currents, turbulence, and tides). The tower's stability also permits the use of instruments such as television and motion-picture cameras and sound transducers. These latter require constancy in depth and orientation for optimum efficiency.



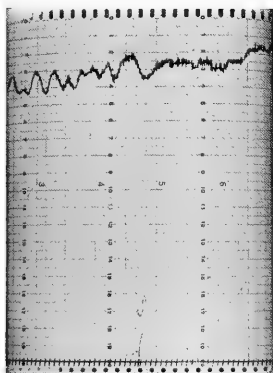


The angled legs, reinforced heavy steel construction, and use of anchoring pins driven in the sea floor give the tower great stability.

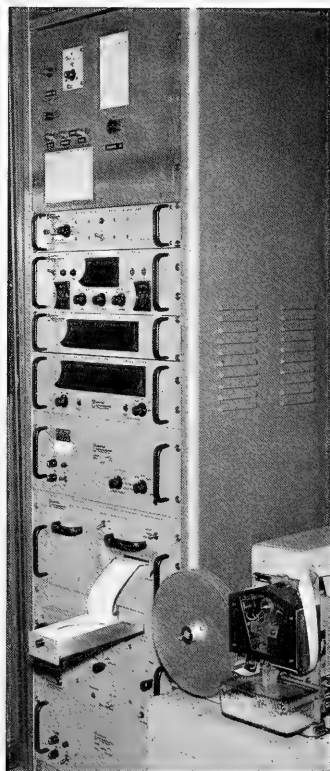
PERMANENCE

The stability and fixed location of the tower make it useful for studies that could not be accomplished economically or efficiently from surface craft. An example is the making of long-term measurements. Many of the instruments mounted on or adjacent to the tower structure are capable of continuously recording oceanographic variables. Examples are shown on this and the following page. These instruments can operate unattended day and night under all weather conditions. The long-term data recordings obtained, covering weeks and months, are used to identify and measure cycles not registered by short-period observations.

Because of its permanency, fixed location, and continuous operation year in and year out, the tower permits operations to be scheduled and planned more easily and efficiently than would be possible with movable surface craft.



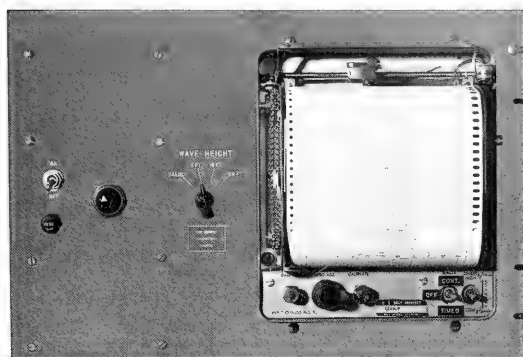
Time vs depth recording from isotherm follower.



Data system that records and prints on punched tape temperature sensed by thermally lagged thermistor beads on tower leg.



Anemometer.



Swell recorder.



Installing tide gauge.

ECONOMY

The tower is far more economical than a ship for shallow-water oceanographic investigations.

Although direct comparisons are not entirely valid, some generalities may be made. The initial cost of the tower was only about 1/15 that of an average oceanographic ship. Maintenance costs, such as painting, cathodic protection, utilities, and replacement of worn parts and cables, are only about 1/8 as much as a ship. Also, manpower utilization is more efficient. Whereas aboard ship most personnel are concerned with ship-handling, on the tower practically all the human effort goes to the scientific projects on hand.

In only one year, the savings realized between the cost of operating the tower and the cost of operating an average oceanographic ship could easily amount to the original cost of the tower. Furthermore, the operational costs of the tower may be kept within stringent budgetary requirements.

Here a working party arrives at the tower. The facility is used by an average of four or five persons per day throughout the year. But it can accommodate several more if the research requires. On the other hand, many measurements are carried out while the tower is completely unattended.





OPERATING COST	
TOWER	\$
SHIP	\$ \$ \$ \$ \$ \$ \$ \$

LABORATORY-LIKE CONDITIONS

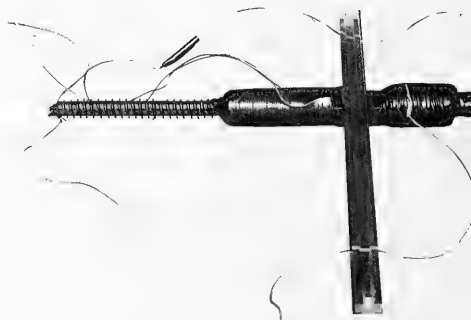
Tower facilities duplicate in many respects those found in the laboratory, and therefore permit a wide spectrum of controlled studies.

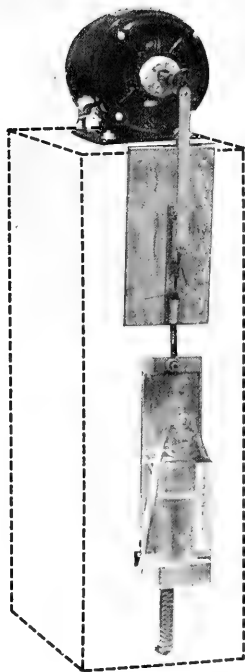
Because of the absence of motion, sensitive instruments such as resonant cavity chambers, microscopes, and other optical equipment can be operated. Acoustic studies benefit from the low underwater ambient noise level and from the low self-noise level. There is neither generator noise nor electrical interference because power is supplied from shore. Other laboratory-like conditions are: the ability to maintain nearly constant room temperature; the convenient access to compressed-air and constant-vacuum systems; the stable power supply (voltage, frequency), which permits operation of recording equipment at constant speeds and known outputs; and the ready availability of a wide variety of measurement and test instruments.



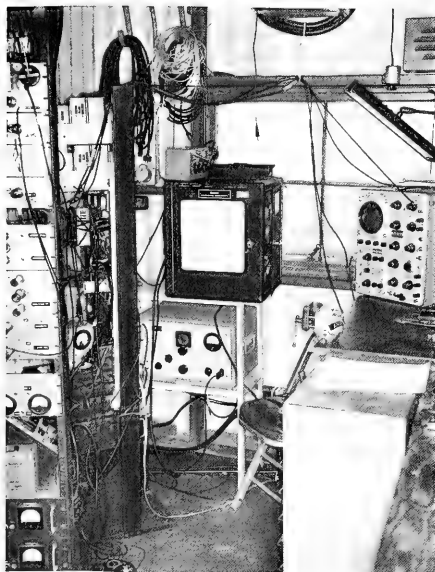
Filtering microorganisms from freshly collected sea-water samples, through millipore filters, under conditions of constant vacuum.

Subjecting planktonic organisms to magnetic fields.





Determining the foaming properties of sea water with a water sample shaker.



Electronic recording instruments requiring a stable power supply are located in a thermally controlled room.



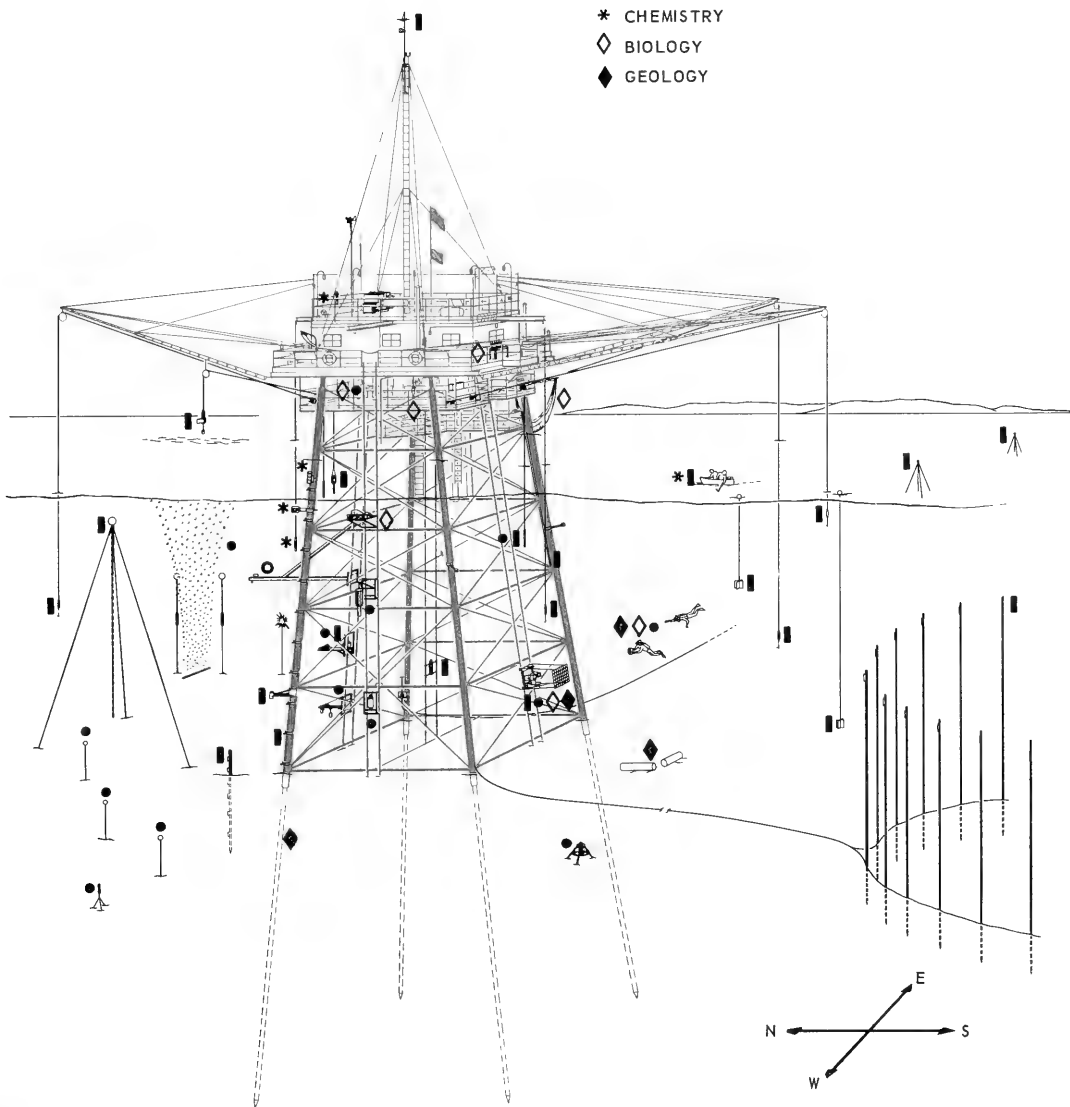
Measuring the sound attenuation caused by plankton with a resonant cavity chamber and recorder.

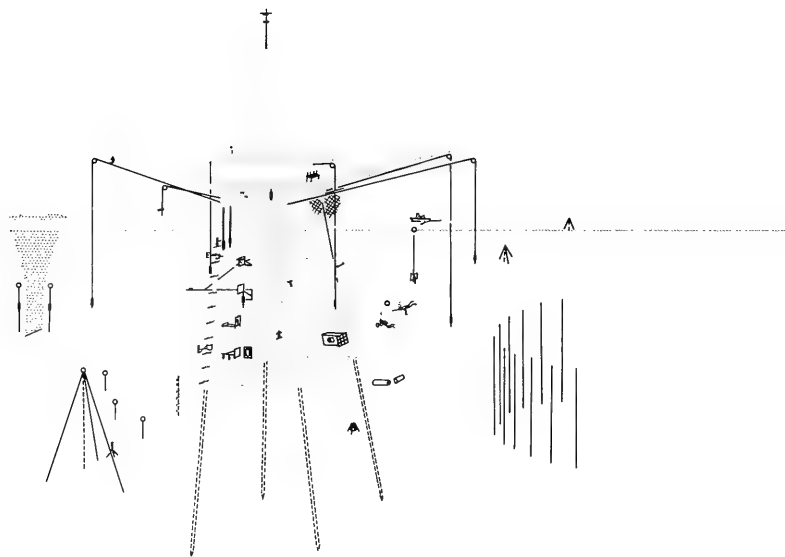
VERSATILITY

The tower is versatile. It is well suited for studies of the atmosphere, the shallow-water oceanic environment, and the sea floor. Several investigations -- related or unrelated -- can be conducted simultaneously from its stable platform. It is adapted not only for work on NEL's problems but those of other activities as well. And it has unique value for oceanographic research in three dimensions (depth, distance, time) when it is coupled with remote instrumentation, such as sensors anchored on the sea floor, or linked with a moving vessel, such as a ship or diving saucer.

The tower's versatility is demonstrated by the wide variety of sensors and instruments located above the water, throughout the water column, and on or under the sea floor adjacent to the tower. Tower studies emphasize factors affecting propagation, transmission, and reception of underwater-sound signals.

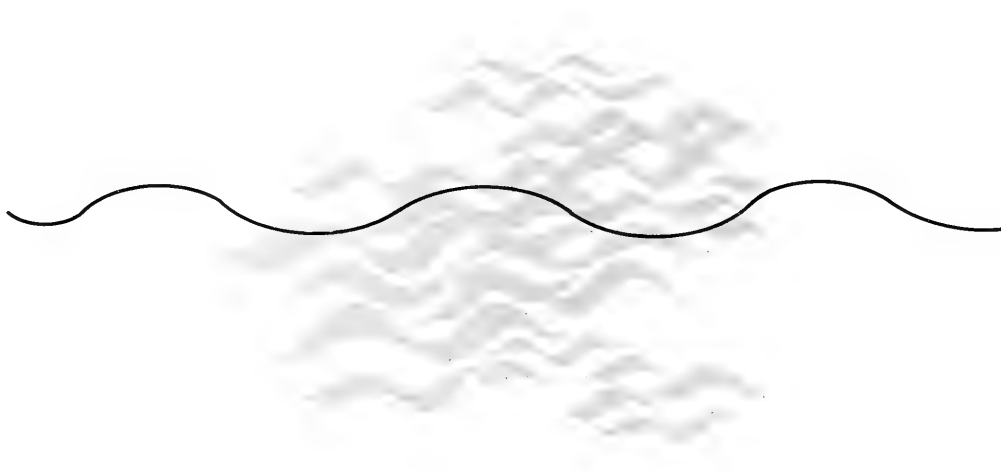
- WATER MOTION
- ACOUSTICS
- ELECTROMAGNETICS
- * CHEMISTRY
- ◇ BIOLOGY
- ◆ GEOLOGY





PART II.

Tower investigations are centered in six key areas. The following text summarizes some of the studies that have been made in these areas, and shows techniques, procedures, and instrumentation that have been found to be valuable in the work.



WATER MOTION STUDIES

Water movement throughout the entire water column is the most intensively studied variable at the tower, for it affects surface and subsurface navigation, acoustic transmission, and the permanence of equipment placed on the sea floor.

The water motions most studied are the large subsurface slow-motion undulations called internal waves.

Other slow motions are related to tide and seiches. The more rapid motions are caused by swell and wind waves. All of these influence the physical, chemical, acoustic, and biological structure of the marine environment.

INTERNAL WAVES

Thermal structure

Horizontal currents

Vertical currents and turbulence

Speed, height, and direction of propagation

Coherence

Sea-surface slicks

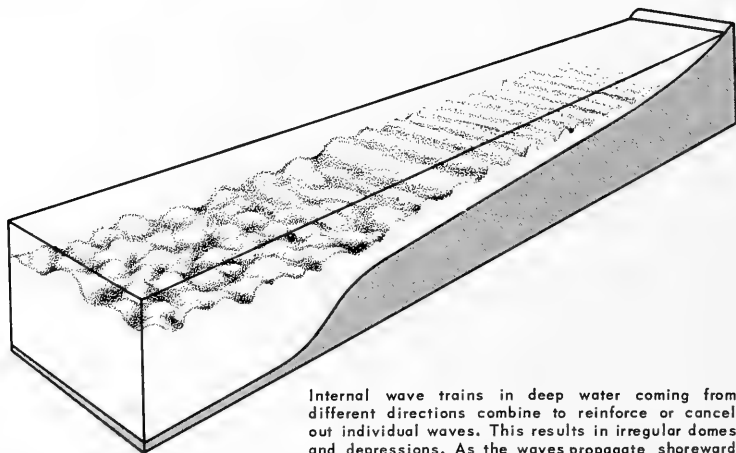
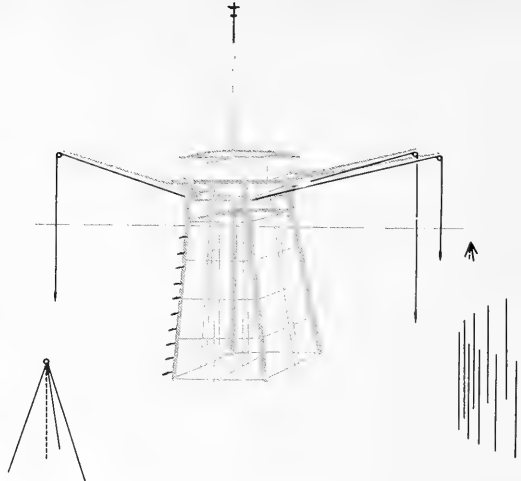
SURFACE TEMPERATURE

SWELL AND WIND WAVES

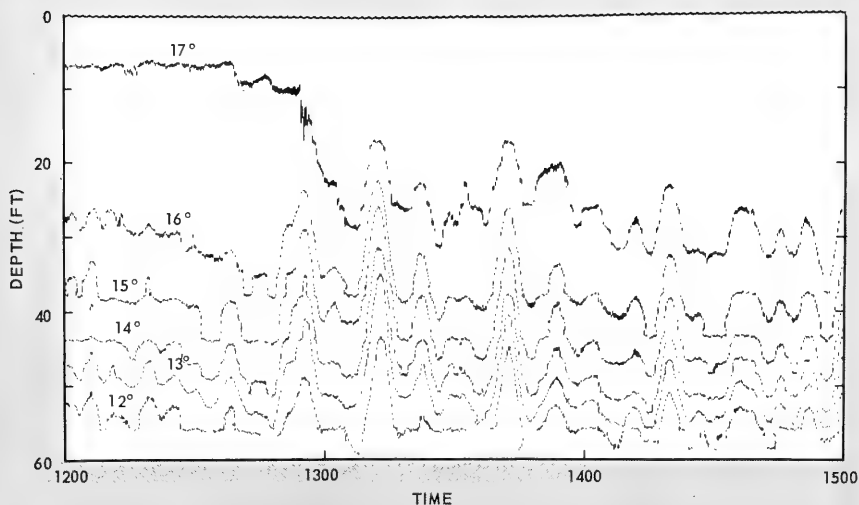
Internal Waves

Internal waves are found between density layers in the sea. They can be caused by flow over an irregular bottom, atmospheric disturbances, tidal forces, and/or shear flow. They have amplitudes considerably larger than ordinary surface gravity waves and propagate at a much slower velocity. The internal wave periods at the tower range from a few minutes to long diurnal oscillations.

At the relatively shallow tower site, the vertical density structure may normally be considered as a two-layer system of warmer and colder water separated by a thermocline. Under these conditions, only one mode of oscillation can exist. The internal waves at different levels are usually in phase with each other, and the greatest vertical displacement of water particles takes place at the thermocline. In rare cases a double thermocline may resonate.



Internal wave trains in deep water coming from different directions combine to reinforce or cancel out individual waves. This results in irregular domes and depressions. As the waves propagate shoreward over the continental shelf, they tend to form into long crests.



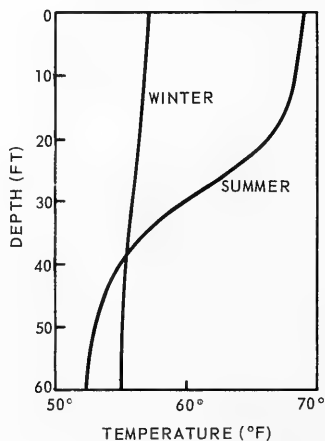
The presence and movement of internal waves at the tower are charted by the continuous measurement of the thermal structure. During the summer there are many small internal waves which have periods of 7 to 10 minutes. These waves are all nearly in phase throughout the water column. This recording also shows the usual afternoon lowering of the thermocline.

Thermal Structure Measurement

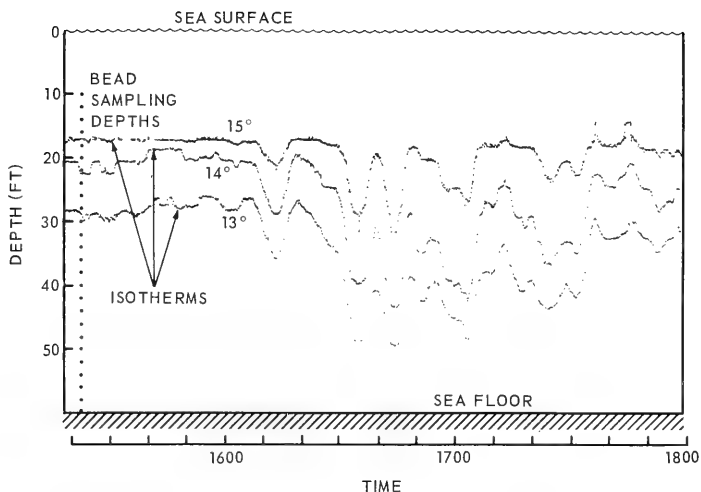
The vertical thermal structure is measured by means of bathythermographs, isotherm followers, and thermistor bead sensors. The thermistor beads are permanently affixed to the tower, floated down from buoys, or suspended at 2-foot intervals in a vertical string from a taut-wire buoy system.

Long-period thermal structure data are obtained from thermistor beads mounted at 6-foot intervals down one tower leg. These are thermally lagged so that the response time (τ) is equal to 20 minutes. Temperatures are printed on a digitized recorder, which is programmed for sequential interrogation of each sensor every 10 minutes. For special heat flow and insulation studies, four similarly lagged beads extend into the sea floor.

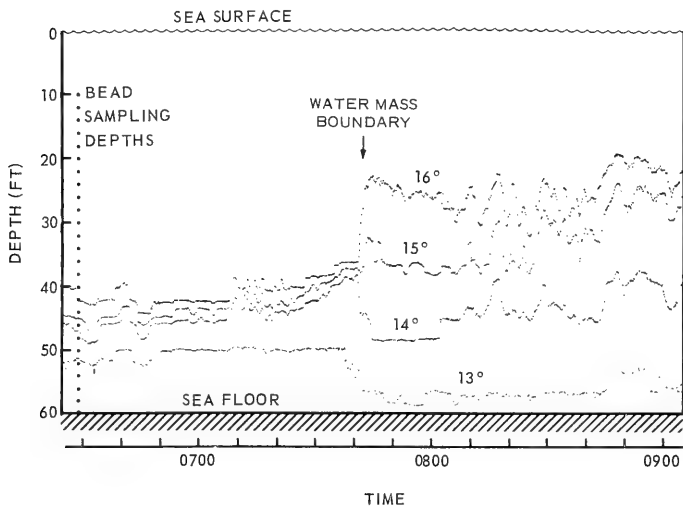
The closely spaced, more rapid response beads ($\tau = 20$ seconds) in a taut-wire buoy arrangement record the most detailed thermal structure. Here the temperature is referenced to the bottom rather than to the surface. This method shows the structure near the sea floor in more detail, since sampling is less influenced by surface action. The data are recorded in analog form as well as on punched tape. Prediction of thermal structure is one of the objectives of these studies.



The temperature structure of the water at the tower in summer contains a strong thermocline, while in winter the water is nearly isothermal. The near-bottom water is colder in summer than in winter because of upwelling.



Thermistor bead sensors are suspended vertically 2 feet apart. The signals from the sensors are interpolated electronically and recorded as whole degree centigrade isotherms. The thermal structure (above) is in a time-depth analog presentation 9 inches wide and recorded at 10 minutes per inch. The internal waves are almost always present.



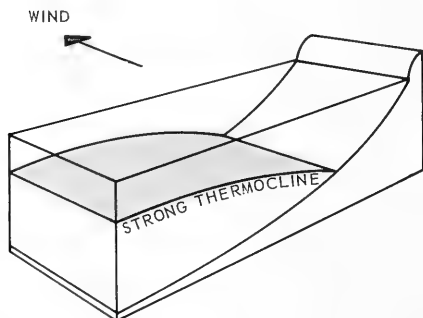
Abrupt changes in depth occurring in some isotherms are caused by water mass boundaries moving past the tower. The depth of the isotherms comprising the thermocline is a principal study.

THERMAL STRUCTURE PREDICTION

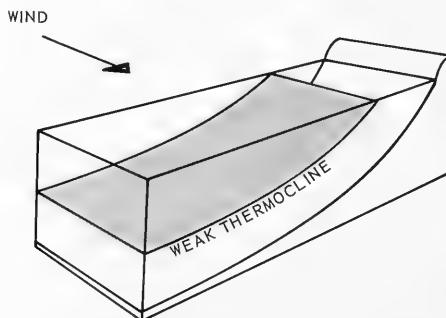
The Navy needs to predict thermocline depth and strength to make efficient use of sonar equipment. Tower studies have established that these predictions can be successfully made in the summer months by using wind speed and direction and tide height data.

The interrelationships between wind, tide, and thermocline were established by continuously recording these parameters throughout one summer. From this study, empirical equations have been developed. It was established that the nearly semidiurnal tide height is of primary importance and that the diurnal wind speed and direction (nearly parallel to the coast in accordance with the Ekman effect) is of secondary importance. Since the thermocline response is 4 hours later for tide and 15 hours for wind, it is possible to predict in advance the thermocline change at the tower within accuracies of practical limits.

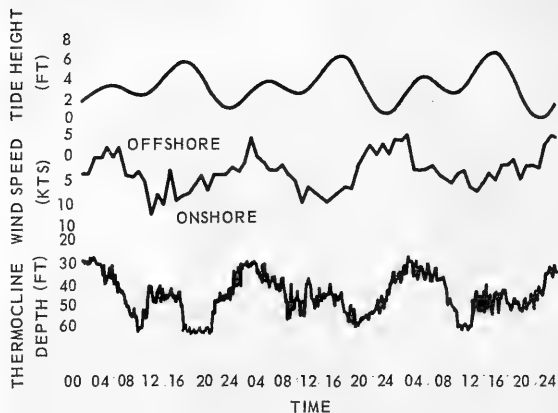
The thermocline goes through cyclic variations in strength that correspond with the tide. The descending thermocline is stronger than the ascending one. The temperature gradient in descent is approximately 0.3 degree C/ft, and in ascent it is approximately 0.1 degree C/ft.



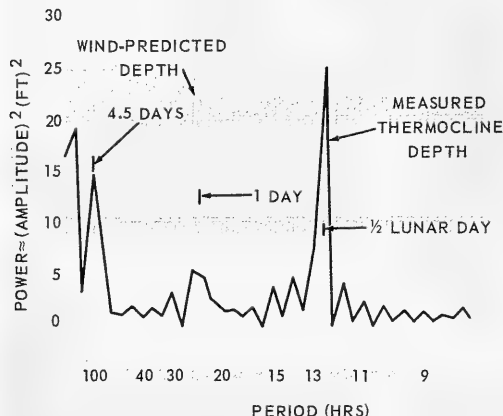
Diurnal cycles in sea breezes normally cause a shoreward (left) and offshoreward (right) displacement of surface water, in accordance with the Ekman effect. The surface-water displacement is such that the thermocline reaches a maximum depth about 1800 hours and a minimum depth in the early morning. Such fluctuations in the thermocline level may amount to as much as 30 feet in 2 hours.



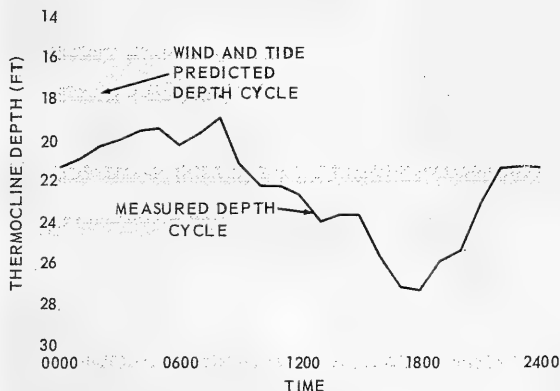
The semidiurnal cycle in tide height and the diurnal cycle in wind direction and speed are both reflected in the depth of the thermocline. The graphs show a 3-day comparison. Vertical lines are 4 hours apart.



The power spectra reveal peaks at 4.5- and 1-day cycles in both wind-predicted thermocline and measured thermocline depths. The tide is solely responsible for the half lunar cycle peak in the observed thermocline depth.



The tide-wind-thermocline relationship makes it possible to predict thermocline depths from wind speed and direction and semidiurnal tide level. A plot of the measured thermocline depths averaged over 30 days shows a close agreement with predicted thermocline depths. (Standard deviation of hourly values is ± 13 feet, standard deviation of daily values is ± 6 feet).

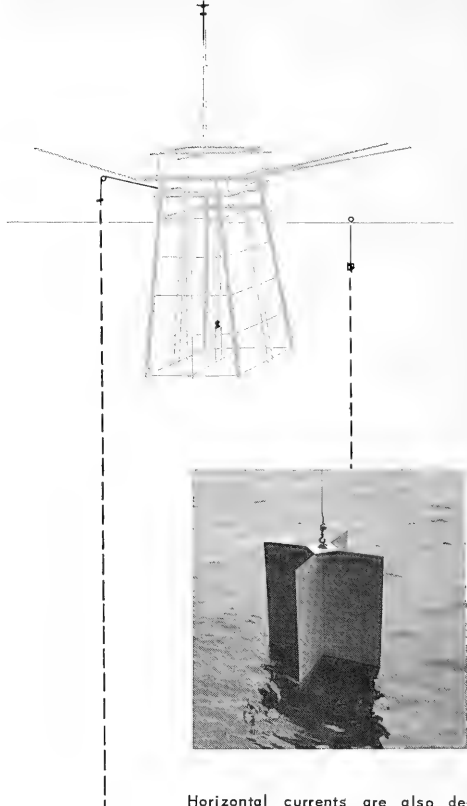


HORIZONTAL CURRENTS

The dominant horizontal current in a shallow sea is produced by the short-period, high-speed orbital motion of surface waves. These currents are modified by the prevailing coastal, geostrophic, tidal, and wind-driven currents.

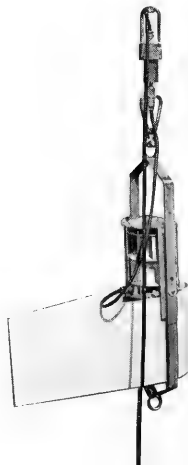
An important low-speed current pattern is produced by the orbital motion of long-period internal waves. The resulting horizontal current patterns are detected and measured at the tower with standard oceanographic current meters and tracking floats which suspend vaned drogues at various depths.

One type of water flow is caused by the daytime coastal winds which produce a shoreward-moving surface current. As a result, the subsurface water flows offshore during the day and a reverse flow takes place at night.



Horizontal currents are also determined by measuring the movement of float-suspended vaned drogues (above). The drogues are positioned at predetermined depths, usually above and below the thermocline. The surface float is tracked by transit and camera from the tower's upper deck. Cameras mounted on kites have also been used to photograph the sea surface.

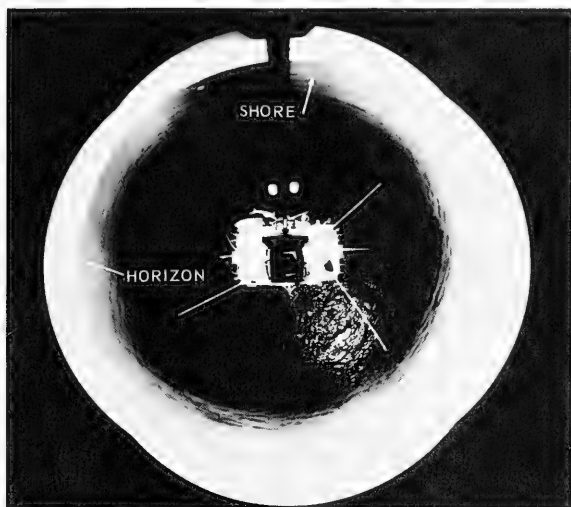
Horizontal currents are measured with several types of current meters. This one from BuShips charts current direction and speed. It is being lowered from the tower boom on a single support wire. For directional orientation, other types of meters utilize twin guide wires extending from the ocean floor to the top of the instrument house. The greatest problem, yet unresolved, is the inability to separate short period, rapid, irregular wave motions from slow coastal drift.



Time-lapse photography of current effects is accomplished with this motion-picture camera. It is mounted beneath a convex mirror which reflects the sea surface to the horizon in a 360-degree arc. The camera unit is raised to the top of the 40-foot mast for operation. It takes photographs at 3- to 5-second intervals. For viewing, these films are shown at about 100 times normal speed. Beside drogue-tracking, the pictures are also used to study the motion of sea-surface slicks.



Drogue movement measurements by time-lapse photography show that the horizontal current flow is strongest near the surface (5 feet deep), in the water column above the thermocline. Speeds to 0.7 knot were recorded. Other readings at 40 feet (below the thermocline) were around 0.2 knot. The 360-degree surface photographs used in this study also showed that the direction of water flow was variable and was mainly related to wind and tide.



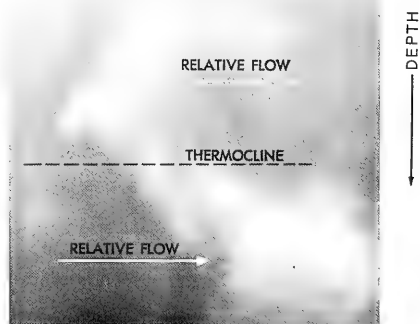
VERTICAL CURRENTS AND TURBULENCE

The tower's TV installation has shown that the dominant motion of water particles is orbital. The nearly circular motion near the surface is modified with depth until along the sea floor it becomes a horizontal surge.

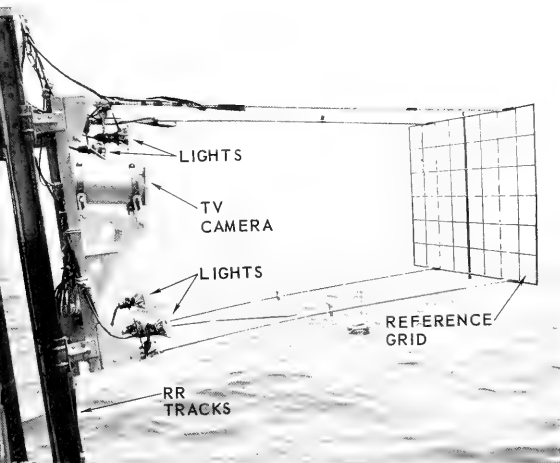
The measurement technique for vertical motion is to attach nylon streamers to the TV's reference grid. The streamers rotate in circular patterns as surface and/or internal waves move past the grid. This permits the study of orbital motion and turbulence.

The movement of the streamers is not continuous. Intermittent pauses at an upward or a downward position reveal the zones of divergence and convergence caused by passing internal waves. Downward motion can be observed between the crest and the following trough; upward motion takes place between the trough and the following crest.

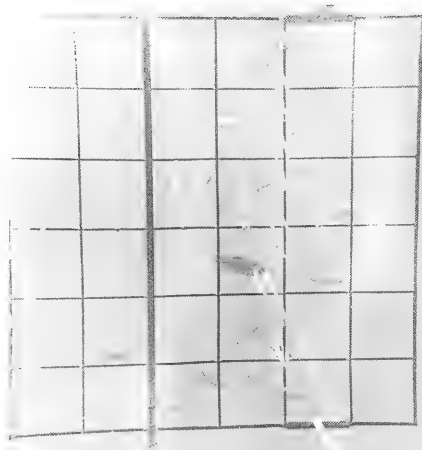
Vertical motion caused by internal waves (up to 15 feet per minute) is found in the thermocline.



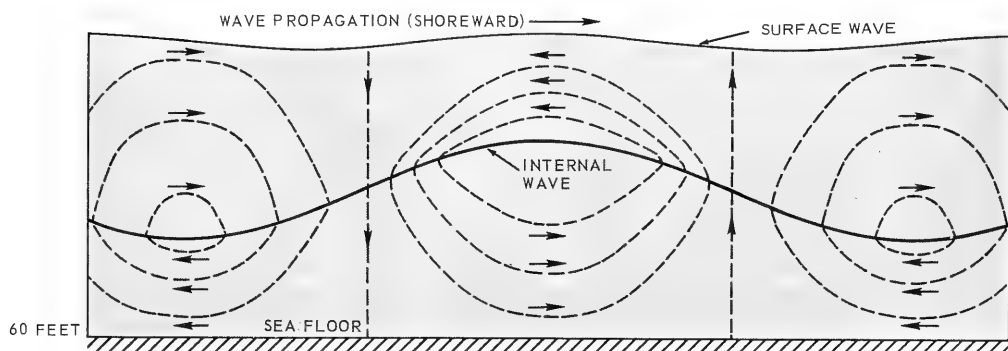
The displacement of clouds of dye dropped vertically through the thermocline demonstrates the orbital circulation associated with internal waves.



Current direction is measured with a reference grid having nylon streamers. The streamers, which have nearly neutral buoyancy, are used as inclinometers. The grid is oriented normal to the direction of propagation of surface and internal waves, in order to detect orbital motion in the vertical plane. Operation is monitored by TV and recorded on motion-picture film.



The central member of the reference grid is a tube which contains dye. The dye extrudes through small openings. The flow patterns produced are used to study turbulence in the thermocline. Under the divergent circulation conditions shown, even fish must swim down to maintain the same depth.



Analysis of streamer and dye movement produces this schematic of water particle flow. White lines are streamlines in an advancing surface wave. Black lines are streamlines in a progressive internal wave. Wave propagation is from left to right.

SPEED, HEIGHT, AND PROPAGATION DIRECTION

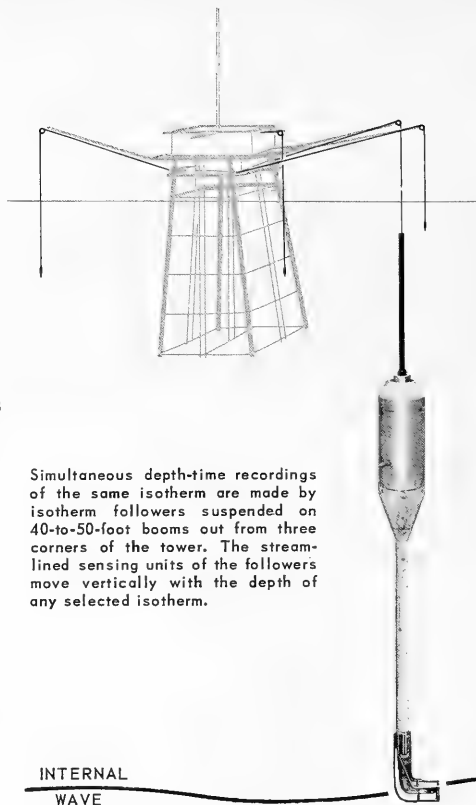
The speed, height, and direction of propagation of internal waves at the tower are determined by three NEL-developed isotherm follower units. As the depth of an isotherm changes, signals from a sensor suspended in the thermocline create an imbalance in the bridge circuit. The circuit in turn causes a winch to raise or lower the sensor. Thus the vertical oscillation is followed as the isotherm passes the tower.

Approximately 90 percent of the internal waves measured propagated in a westerly and southwesterly direction. The speed of the progressive internal waves, c , varies directly with the thickness of the two layers and their density. For internal waves that are long compared with the water depth

$$c^2 = \frac{ghh'}{h+h'} \cdot \frac{\rho-\rho'}{\rho}$$

Where h' is the thickness of the upper layer, h is the thickness of the lower water layer, and ρ' and ρ are the respective water densities. In summer, the speed is about 0.3 knot.

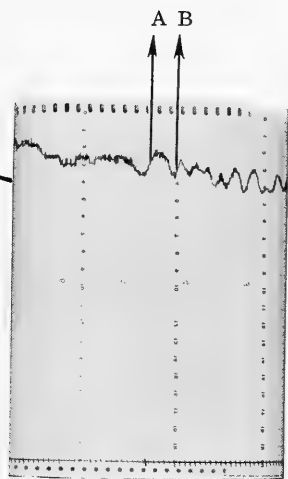
Thus as internal waves approach the shore, they decelerate, become more closely spaced, refract, develop long crests, and finally move onshore.



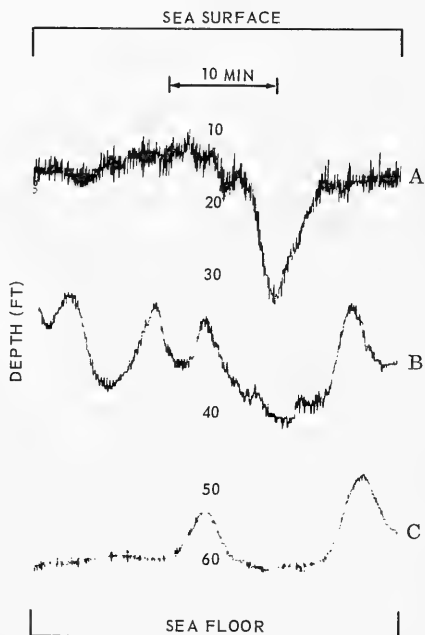
The short-period waves described by an isotherm in the middle of a summer thermocline show a median height of 5.4 feet, a period of 7.3 minutes, and a speed of about 0.3 knot.



The speed and direction of internal waves are also determined visually and photographically by observing the movements of sea-surface slicks. The long slick lines are found at the surface above the convergence zone, which is behind the crest of the internal waves. When the internal wave crests are near the sea surface, the surface becomes rougher, thus identifying the orientation and phase of the internal wave.



Isotherms outlining the shape of internal waves change as the thermocline approaches either the sea floor or the surface. These are three typical recordings of isotherm depths when the thermocline is: (A) near the surface; (B) at mid-depth around 30 feet; and (C) near the sea floor.

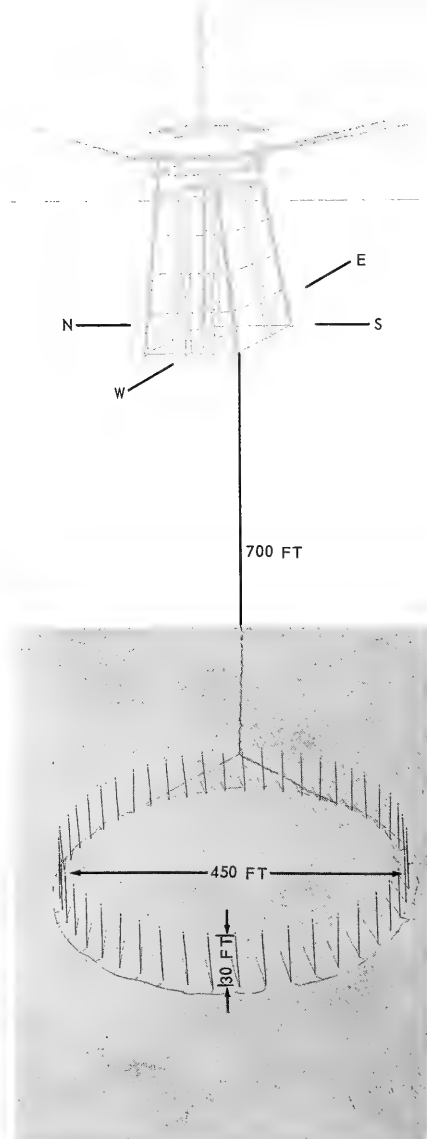


COHERENCE

To study the spatial coherence of internal waves, two-dimensional horizontal thermal measurements are made as the waves move shoreward in the vicinity of the tower. This is done with a circular thermistor array 450 feet in diameter. The temperature signals from the array are recorded on the tower in analog and digital form.

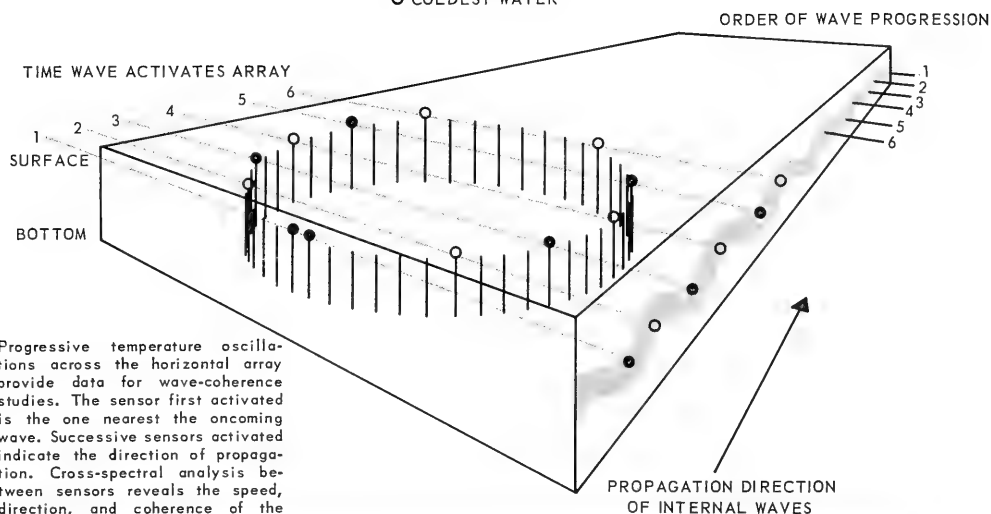
Several long periods of continuous coherence data have been compiled, together with simultaneous recordings of acoustic transmission loss information. Preliminary analysis indicates that the beam width of the direction of internal wave propagation is about 0.4 radian. Other information reveals that internal waves of high frequency are coherent for distances of over half a wavelength.

Observation and measurement of the orientation and movement of sea-surface slicks also provide information on the coherence of internal waves.



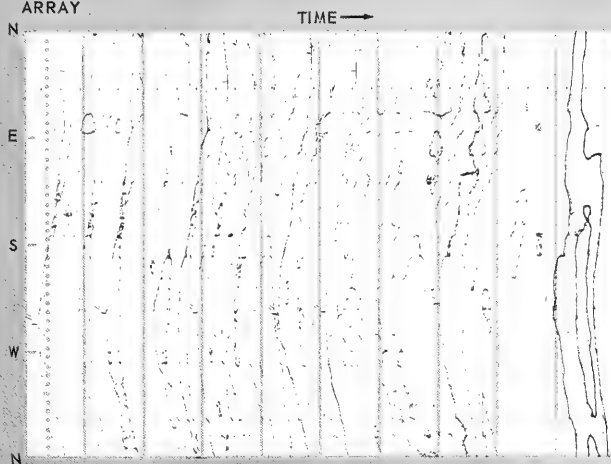
Internal wave coherence is investigated with this circular array of 48 sensors. The array is installed in a horizontal plane at mid-depth, 30 feet from the sea floor and 700 feet southwest of the tower. At this location the tower is too far away to affect the internal wave structure. Each sensor is cable-connected to the tower.

- WARMEST WATER
- COLDEST WATER



Progressive temperature oscillations across the horizontal array provide data for wave-coherence studies. The sensor first activated is the one nearest the oncoming wave. Successive sensors activated indicate the direction of propagation. Cross-spectral analysis between sensors reveals the speed, direction, and coherence of the internal wave.

POSITION OF
SENSORS IN
ARRAY



Analog recording of the temperature data from the array. Data are presented as isotherms on a space-time plot. Since the internal waves propagate from a west-southwest direction, the isothermal curves on the analog recording bulge to the left, or earlier position with respect to time. Analyses are made from parallel recorded digital data.

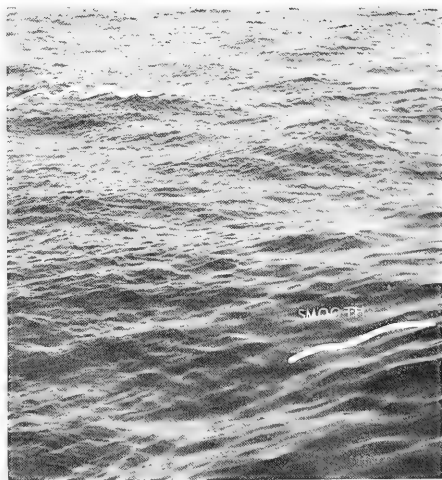
SEA-SURFACE SLICKS

Sea-surface slicks are characterized by capillary waves that are smaller than those in adjacent waters. The slicks appear glassy because they reflect the sky better than does the rougher water outside the area.

Slick bands, occurring where lighter-than-water film is concentrated, are related to the downward motion of internal waves. These bands signal the presence of active sinking zones.

Sea-surface film from near the tower has been collected. It appears to be composed of organic compounds, probably derived from decomposed organisms. The surface tension of seawater samples from outside a slick area was found to range between 70.5 and 73.5 dynes per centimeter at 20 degrees centigrade, while specimens collected in slick areas gave lower surface tension values of from 49.2 to 68.8 dynes per centimeter.

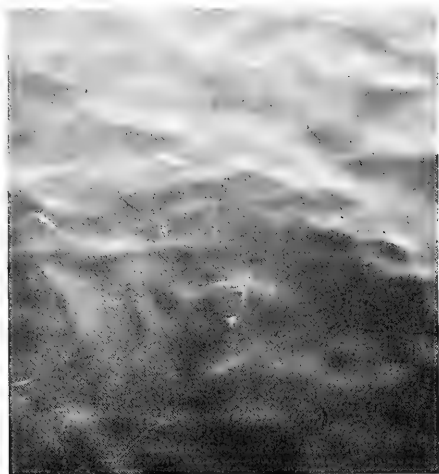
The orientation, speed, and direction of internal wave movement may be determined from time-lapse photographs of slick bands. This information gives a three-dimensional perspective of subsurface thermal structure and movement. However, under conditions of high wind speeds the internal wave slicks are broken up. The slicks then orient a little to the right of the wind direction.



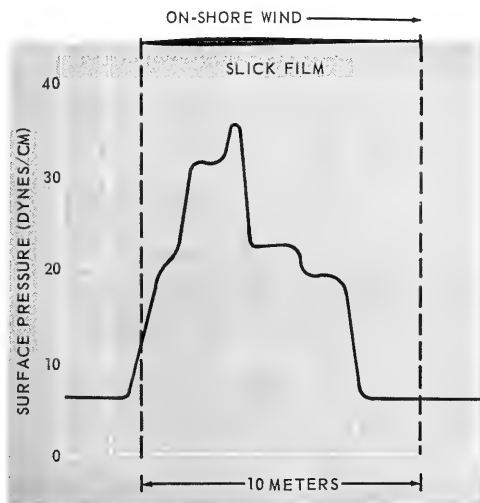
The film on the slick reduces both surface tension and the small capillary waves, thus making the area smoother and increasing its ability to reflect light.



Ragged bands and patches of a surface slick give the sea around the tower a glassy appearance. Covering as much as 10 percent of the surface, slicks usually orient themselves in lines parallel to the shore. The time of the slick's arrival at the tower is noted and correlated with recordings of the thermal structure and other phenomena.



The slick film collected from the tower appears oily and frequently contains pieces of seaweed, foam, and other debris.

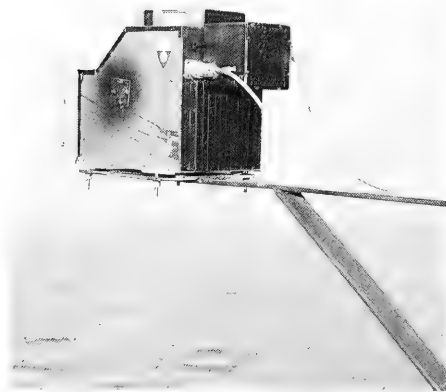


Surface pressure across slicks was studied by dropping various concentrations of oil and alcohol on the surface and noting the spreading effect. In this example the greatest surface pressure is skewed in the upwind direction toward the trailing edge of the slick.

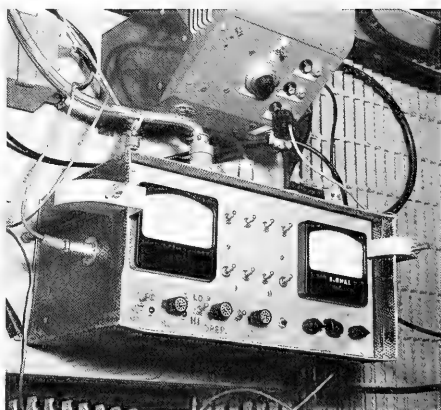
SURFACE TEMPERATURES

Surface-film temperature in a slick has been successfully determined by an infrared sensor at the tower. The sensing equipment consists of an infrared temperature detector, signal-processing electronics, and strip-chart recorder. This noncontact instrument remotely senses radiation in a spectral region (8 to 13 microns) where water is highly emissive but is not reflective. The investigation showed that it is possible to establish water structures and processes in the sea from continuous surface-temperature recordings with an infrared radiometer.

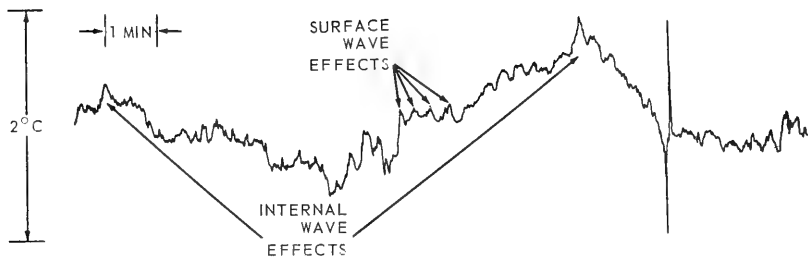
Surface temperatures from the tower are also measured by the bucket-thermometer and other sensors.



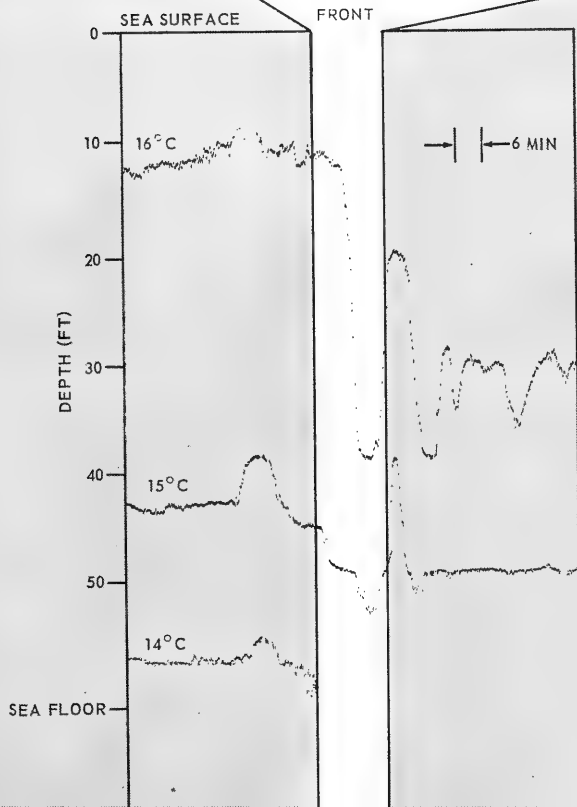
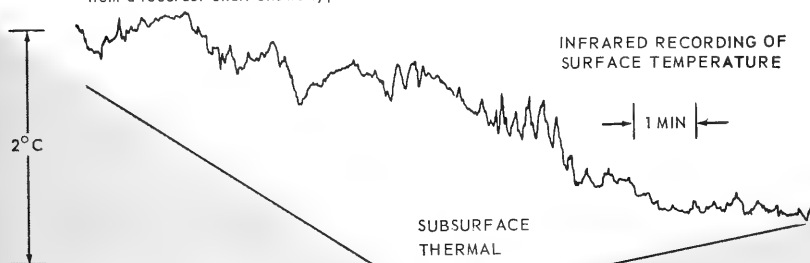
The infrared detector consists of an optical system and thermistor bolometer located 20 feet above the mean tide level. The beam, which is 5 degrees wide, senses 2.4 square feet of the sea surface.



Temperature measurements by the detector are processed by electronic circuitry, amplified, then fed to the strip chart recorder in the instrument house.



Surface temperature variations from such diverse causes as ship's wake, divers working below the thermocline, or passive sea-surface slicks may be measured with the infrared sensor. Other temperature changes have periods corresponding to those of surface and internal waves. Variations as small as 0.1 degree centigrade are detected. This tracing from a recorder chart shows typical fluctuations.



The infrared recording equipment clearly identifies temperature changes associated with thermal fronts, and agrees with the sharply dipping isotherms simultaneously recorded on the vertical temperature array. (Upper curve traced from recorder chart.)

Swell and Wind Waves

The heights and periods of swell and wind waves are used to establish the sea-surface roughness. This is especially important during sound-transmission studies, as these waves reflect and scatter acoustic energy.

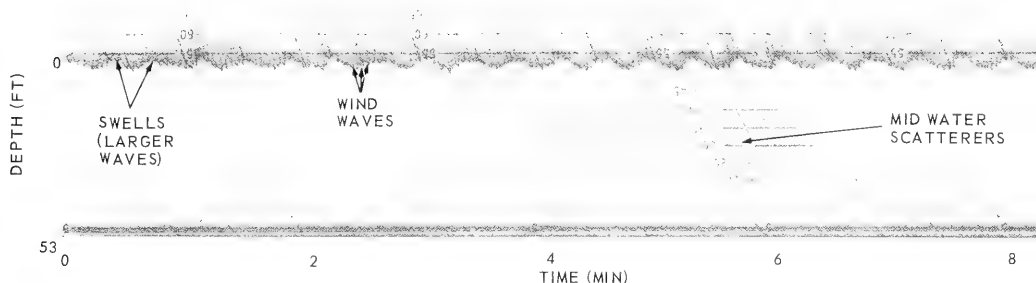
For the measurement of swell, a permanent tower-mounted swell recorder is monitored 15 minutes daily. This provides information on seasonal variation in swell.

Information on wind waves is provided by a vertically directed acoustic transducer which is mounted in a gimbaled tripod on the sea floor. Tower recordings of the strong sound reflections received from the sea surface delineate all types of waves as well as any midwater reflectors.

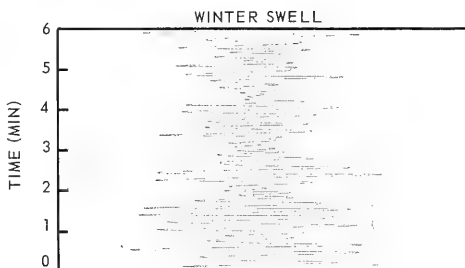
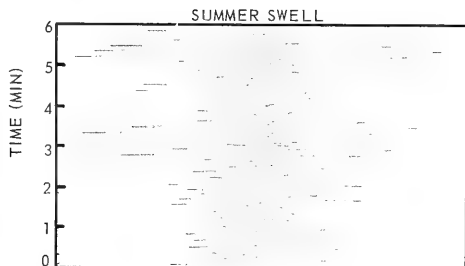
The higher surface waves are associated with local and distant storms. The highest wave observed was 18 feet and occurred during a local storm. These waves travel shoreward and are refracted by the shoaling continental shelf. The average swell period is about 12.5 seconds in summer and 11.5 seconds in winter. The average height of significant waves is greater in the summer than in winter.

To measure the height of swells, a Snodgrass Mark IX pressure sensor is housed 2 feet out from the NW tower leg, 37 feet below the mean sea surface. Pressure is electrically transmitted to a specially adapted recorder in the instrument house. The mounting provides a favorite habitat for marine organisms.





Surface roughness, with small wind waves superimposed on the swell, is recorded by a bottom-mounted transducer. Most detail of the sea surface is obtained by this acoustic method.



Wave recorder has pressure and wave-period factors incorporated in the electronics, so that wave heights can be recorded directly on 0- to 5-, 0- to 10-, or 0- to 20-foot scales, at chart speeds of 12 or 60 inches per hour.

There is a seasonal variation in swell height and period. Such information on sea-surface roughness is needed to interpret variations in acoustic scattering from the upper boundary.



ACOUSTIC STUDIES

Research in acoustics from the tower is concerned with the propagation of subsurface sound signals, and especially with biological and physical factors that interfere with propagation, transmission, and reception. The investigations are centered in seven primary areas:

Biological factors

Ambient sound

Target identification

Acoustic scattering

Sound attenuation (plankton)

Physical factors

Sound attenuation (bubbles)

Sound velocity

Sound transmission

Biological Factors

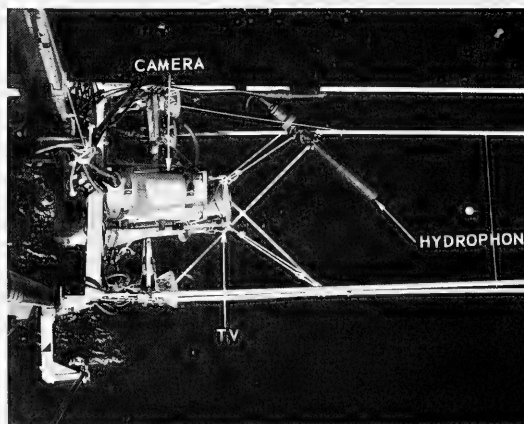
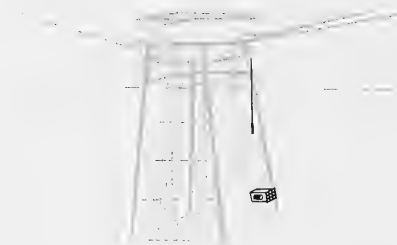
AMBIENT SOUND

Biological and other sounds which contribute to the total ambient noise are identified and measured from the tower.

The low background noise permits the study of a wide variety of sounds of biological origin, and is favorable for high-frequency acoustic tests. There is, however, some low-level water noise below 10 kc/s which is caused by waves surging against the tower framework.

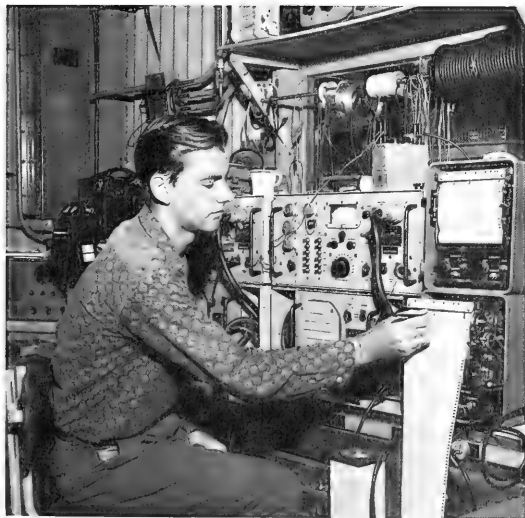
Two distinct periodic variations in underwater noise level are observed. The first has a semidiurnal period in the band between 200 and 1200 c/s. Higher intensities are noted around sunrise and sunset in summer. The second variation has a period of 25 to 40 seconds and is observed only at night and only in the late spring and summer. It is commonly 3 to 6 dB above the background, but a maximum of 16 dB has been recorded. It occurs in the limited 300- to 800-c/s band, with a peak amplitude at 450 c/s.

Both ambient sounds are apparently biological in origin and are related to sandy bottoms. Two members of the croaker family; spotfin, *Roncador stearnsi*; and yellowfin, *Umbrina roncador*, are believed to be largely responsible.

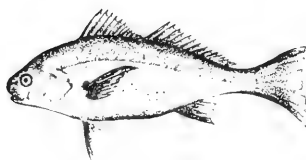


Listening hydrophone is placed in view of the television camera in an attempt to identify the organisms which produce sounds in the sea around the tower. View looking down rail track.

Cyclic fluctuations, frequency, and levels of biological sounds are investigated with sound amplifying and recording equipment (Noise Measuring Set AN/PQM-1A). Since the tower has a low noise level (it contains no generators and all small motors can be stopped during critical experiments), the weak biological sounds can be distinguished from the background.

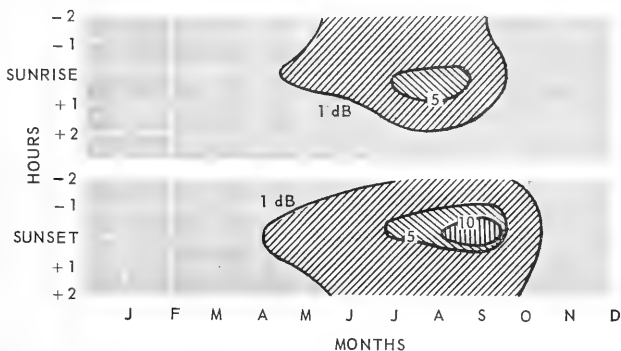


YELLOWFIN CROAKER
Umbrina roncadior



SPOTFIN CROAKER
Roncadior Stearnsi

The long period (25- to 40- second) variations in ambient noise observed in the 300- to 800-c/s band increase in intensity during the late spring and summer months (contoured in 1, 5, and 10 dB above normal background). Intensities reach a maximum just after sunrise and at sunset.



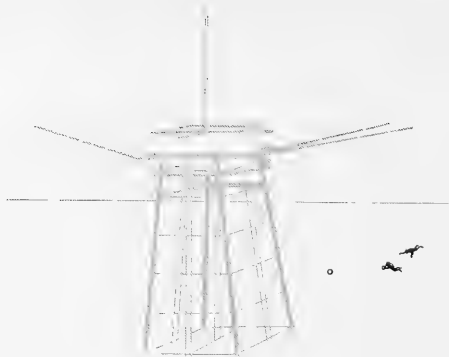
TARGET IDENTIFICATION

The varied fish population that lives and feeds around the tower affords an unusual opportunity to observe and measure the sonar target characteristics of individual species. Identification of fish types by acoustic means has value not only to the Navy but also to commercial fishermen.

One target identification study was conducted by using a diver-held sonar. Sonar reflections from the fish were transmitted by wire to a tape recorder on the tower. The tapes were analyzed for frequency and relative intensity of echoes from individual species and groups. Analysis of these tapes revealed a variation in signal pattern that depended upon the characteristic shape and structure of the individual fish and other objects, the frequency of the sound, and the range of the sonar target.

Studies of the identification of biological organisms by underwater sounds are not limited to the larger animals. Schools of small fish and masses of zooplankton organisms have been observed to cause extensive acoustic scattering.

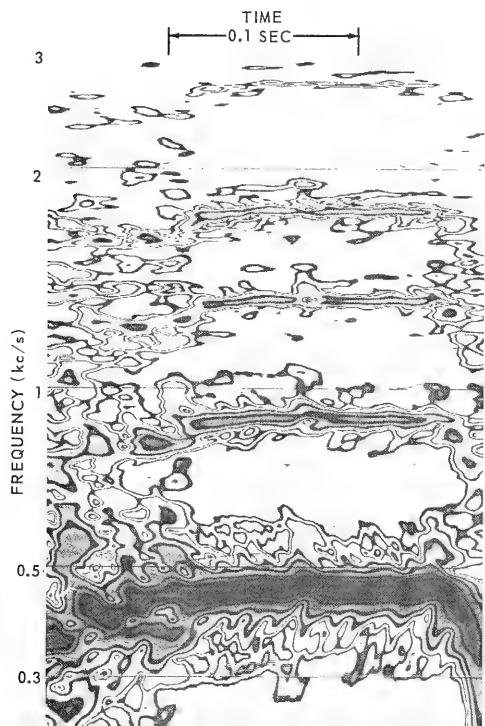
Divers train NEL-developed hand-held sonar (AN/PQS-1B) on various species of fish to record the characteristics of echoes produced. The sonar sweeps from 85 to 55 kc/s in a linear, sawtoothed manner. An air-filled aluminum sphere is suspended in the water and used as a reference target.





SHEEP-HEAD

Acoustic intensity contours provide a frequency-time plot of signals reflected from a large sheep-head, *Pimelometopon pulchrum*. The analysis shows intricate patterns which differentiate this fish from other targets.



JACK MACKEREL

Similar acoustic intensity contours were recorded and analyzed from a school of jack mackerel, *Trachurus symmetricus*. Other fish studied were: halfmoon, *Medialuna californiensis*; grunion, *Leuresthes tenuis*; jacksmelt, *Atherinopsis californiensis*; and topsmelt, *Atherinops affinis*.

Even individual targets as large as scuba divers may be identified from analysis of echo intensity contours and frequency. Contours left are for a female scuba diver 10 feet away.

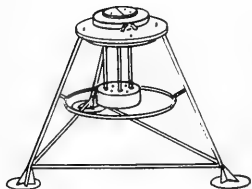
ACOUSTIC SCATTERING

Plankton and other suspended matter which cause echoes when high-frequency sound is directed through water may also produce turbidity. To investigate these acoustic scatterers, an echo sounder was gimballed in a tripod on the sea floor and the sound beam was directed upward. The echograms thus produced show the scattering caused by various organisms in the water column.

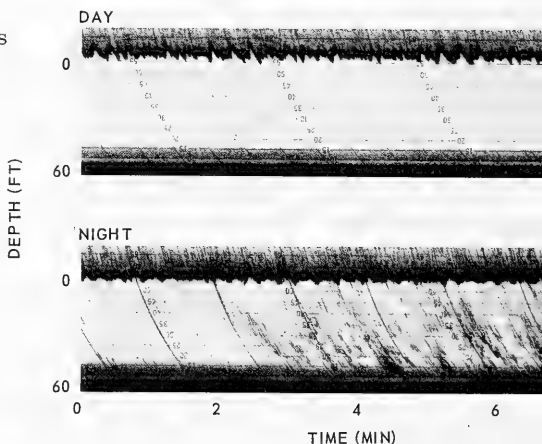
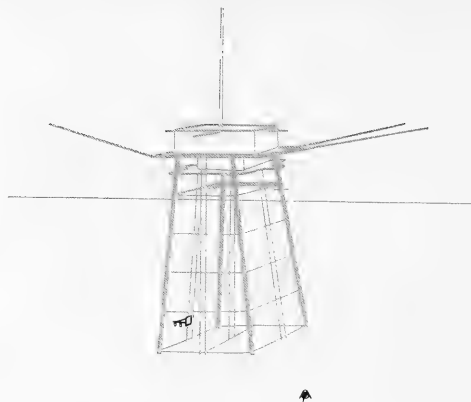
Some acoustic scatterers around the tower have a negative reaction to both natural and artificial illumination. They dive or disperse when an underwater light is turned on. After the light is turned off they return, but not as quickly as they dispersed. They are normally absent during daylight.

These scatterers occur in patches which move toward the coastline from deeper water, or rise from the bottom, at night. The maximum concentrations of scatterers follow the depth of the thermocline. This behavior is similar to that of light scatterers. However, their phototropic behavior is different.

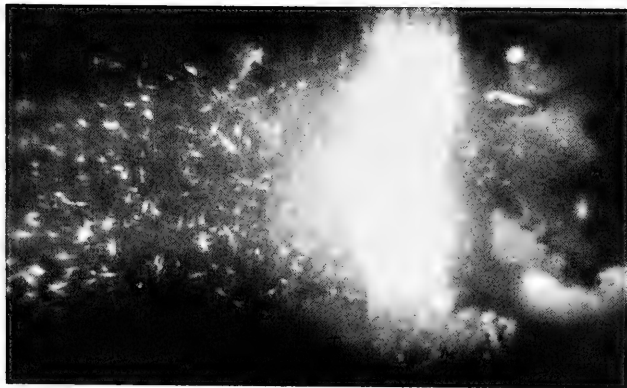
It is thought that one type of acoustic scatterer around the tower is the shrimp-like mysid that characteristically feeds at night. Other types, including fish, are also present.



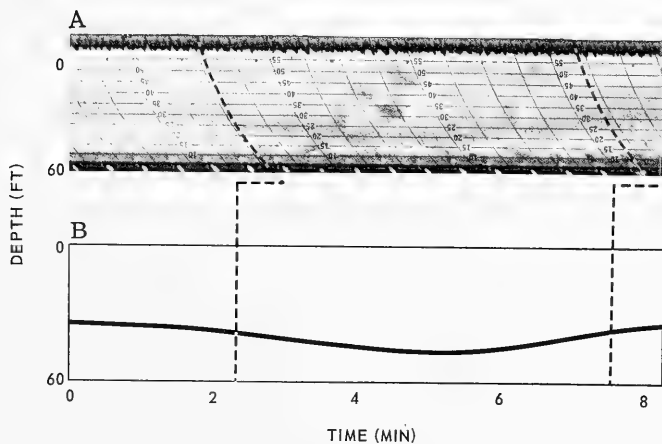
An upward-directed NK-7 transducer is installed on the sea floor to determine the distribution, behavior, and nature of sound-scattering layers. This transducer operates at 21 kc/s with a beam-width of 20 degrees at the 6-dB down points.



Sea floor-to-surface echograms recorded at the tower show that summer scatterers are absent during the day and abundant at night throughout the water column.



Shrimp-like, phototropic mysids were photographed swarming at night. Since they are not present in the water during the day, they are suspected of contributing to the observed acoustic nighttime scattering.



Echogram compared with a recording of an Isotherm movement, shows that the maximum biological acoustic scattering moves vertically with the thermocline. The scatterers undergo 5- to 10-minute periods of oscillation corresponding with the movement of internal waves.

SOUND ATTENUATION (PLANKTON)

Attenuation of sound by plankton organisms and other particulate matter is being investigated with resonant cavity equipment. The cavity resonators have acoustically soft side walls. They are capable of measuring excess attenuation in the 10- to 200-dB/kyd range, at discrete frequencies of 5 and 8 kc/s.

Distilled water or sea water without particulate matter shows no measurable attenuation. However, natural sea water with particulate matter and medium to high oxygen saturation shows excess attenuation throughout the entire range of instrumentation (i. e., 10 to 200 dB/kyd).

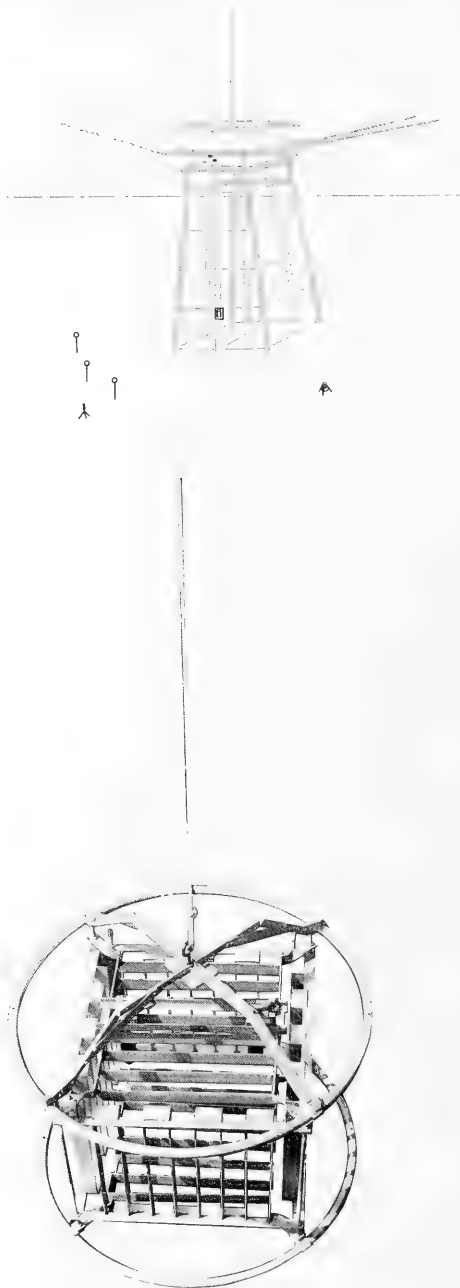
The excess attenuation is defined as:

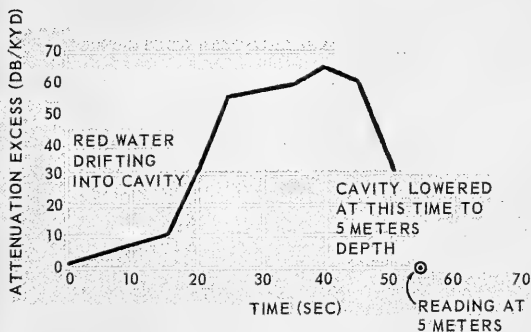
$$a_{\text{ex}} = \left(\frac{1}{T_1} - \frac{1}{T_0} \right) \text{dB/kyd}$$

where T_0 and T_1 are the reverberation times of distilled and plankton filled water, respectively.

One investigation was carried out during the "red tide" bloom, a condition caused by an extremely high concentration of the plankton organism, *Gonyaulax polyedra*. The tower measurements during this "red tide" were supplemented by observations at sea made with a compliant-tube resonant cavity.

The seagoing cavity was constructed as a cage, with the bars made of flattened and therefore compliant tubes. These structures act as pressure-release surfaces in a limited frequency band, but are neither as efficient nor as sensitive as the laboratory equipment used on the tower. The results from both the tower and ships did, however, confirm high acoustic attenuation where the plankton concentration is high.



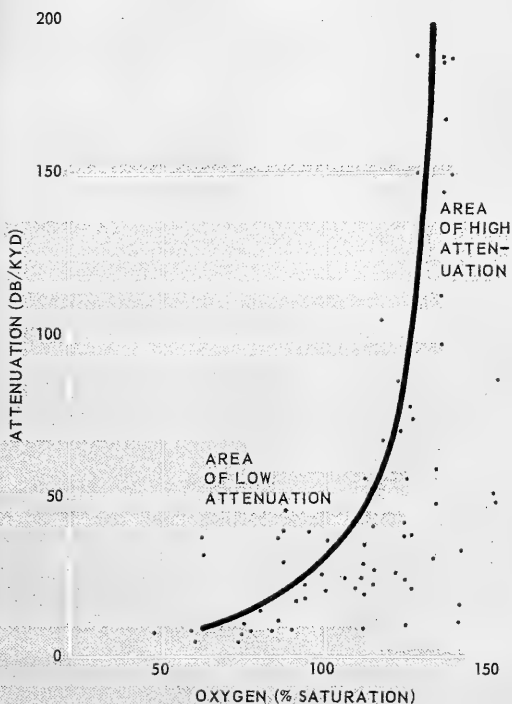


A heavy bloom of *Gonyaulax* plankton ("red tide") drifting through the resonant cavity suspended in the sea caused excess sound attenuation of up to 64 dB/kyd.



Scientist monitors resonant cavity equipment to measure sound attenuation caused by plankton organisms. Resonant cavity measurements require the tower's stable platform and proximity to fresh, live marine organisms.

Data collected by means of the resonant cavity chamber also show the relationship of oxygen saturation of sea water to excess attenuation. When the oxygen saturation is greater than 100 percent, the attenuation is markedly increased.



Physical Factors

SOUND ATTENUATION

(BUBBLES)

Sound attenuation by bubbles is studied at the tower with a bottom-mounted bubble screen, multiple hydrophones, and a sound source. The attenuation is influenced by sound frequency, size and number of bubbles, and other factors. Attenuation as great as 90 percent was found when using a bubble screen 10-feet long which emitted air at 200 cubic feet per minute against a head of 32 pounds per square inch.

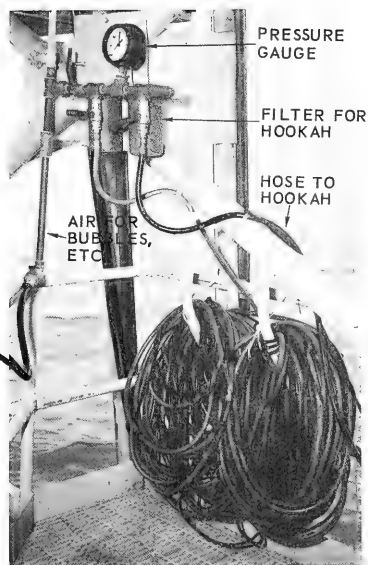
In addition to greatly attenuating the sound, the bubble screen also caused the colder water near the bottom to upwell, forcing the thermocline in the immediate area to rise.

Natural bubbles caused by the breaking white caps (and probably by plankton and fish) are recorded by other acoustic means.



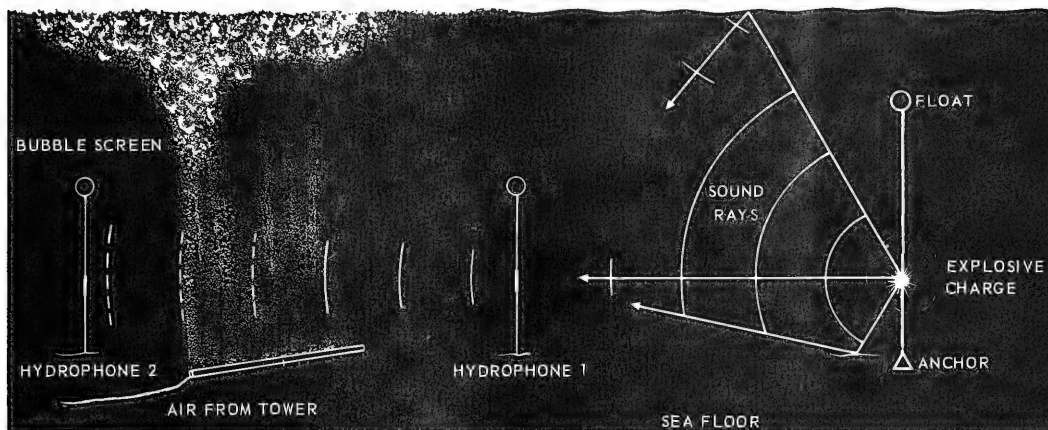
The bubble screen (left on facing page) is created by connecting a hose from the air compressor on the tower to a long multiple-hole pipe (perforations 0.8 mm diameter every 13 mm) mounted on the sea floor. The air released causes a bubble screen which extends from bottom to surface. The bubbles expand and sometime coalesce as they approach the surface.

Sound intensity is measured before and after the sound waves pass through the bubble screen. In one test series, explosive charges (shown to the right) were used as the sound source. The bubble screen greatly reduced the sound intensity.



Compressed air for bubble attenuation work, hookah, and other applications is available on the lower deck. It is valved for single or multiple use. Bubble screen air and hammer hoses are connected to these valves. The bubble screen air flow of 200 cubic feet per minute is valved off.

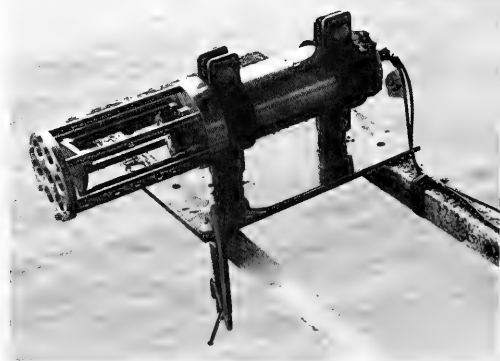
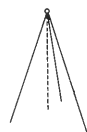
SEA SURFACE



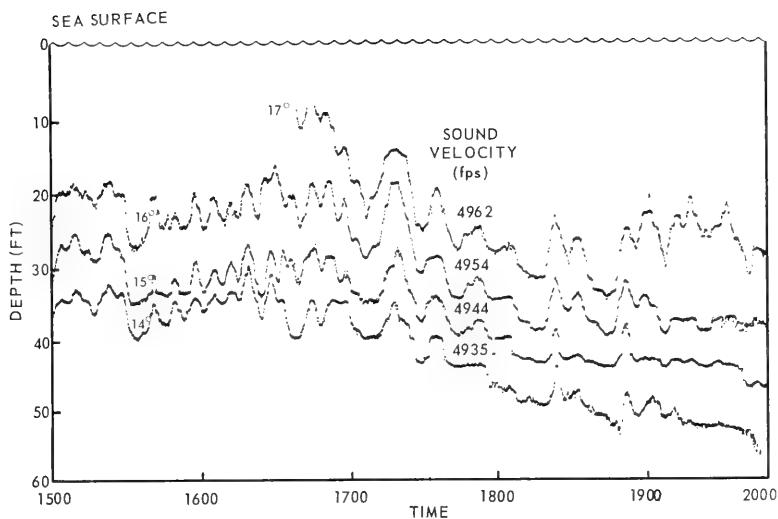
SOUND VELOCITY

The speed of sound at intervals throughout the water column is computed from measurements of temperature, salinity, and pressure. In addition, various sound velocity meters have been tested and used. Some meters were mounted on tower carts for vertical sound-velocity structure measurements, while others were attached to a tripod out from the tower for long-period recording.

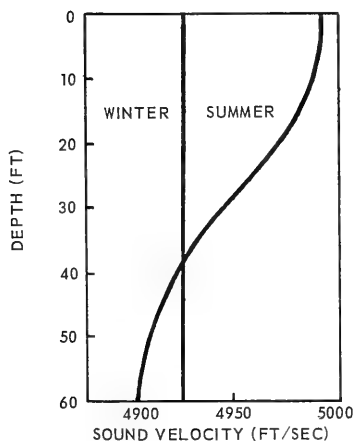
The meters normally utilize sing-around circuits which produce a frequency proportional to the sound velocity. The frequency is recorded digitally and later converted to sound velocity. The data are used for acoustic transmission studies when precise values are required. In other studies, sound velocity is obtained indirectly.



Variable-depth sound velocity meter transmits a pulse of sound. When the pulse is received it triggers a new pulse. This process is continuously repeated over a given path. The pulse repetition frequency is a direct measure of the sound velocity. The signals are carried to digital recorders in the instrument house and the recordings are later converted by machine to correct sound velocity.



Small scale time fluctuations in sound velocity may be approximated from detailed thermal structure, such as shown in this recording made in the summer of 1965. Since the salinity range from surface to bottom is very small, the principal controlling factor is temperature. Thus, from the detailed recordings of thermal structure and depth, the sound velocity corresponding to each isotherm may be computed from the known temperature-salinity-depth relationship. Such sound velocity detail is useful in the study of fluctuations in acoustic transmission.

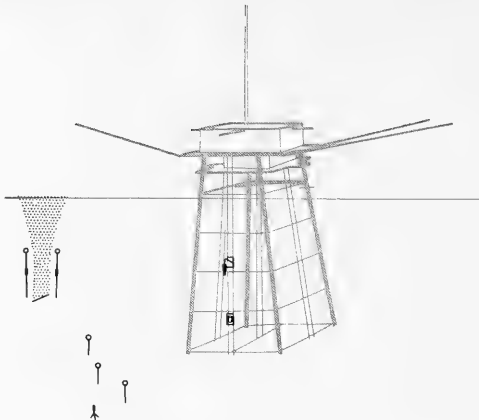


The vertical sound velocity structure, like temperature, changes greatly from summer to winter. Thus different acoustic transmission programs are scheduled to take advantage of the desired sound velocity condition.

SOUND TRANSMISSION

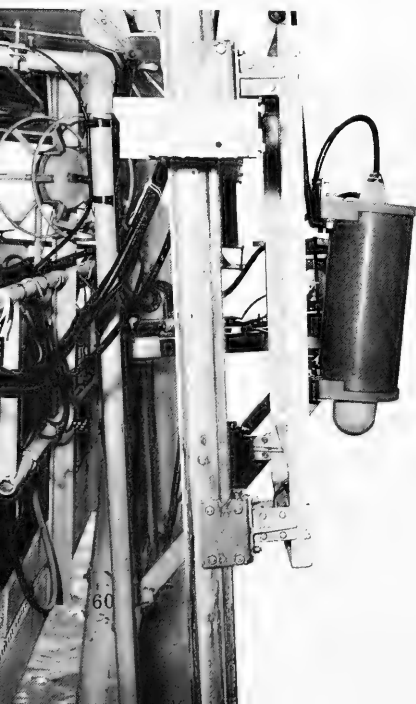
The transmission of sound through the water is greatly affected by internal waves. This is especially true of high-frequency sound. The greatest influence is refraction by the vertical (and horizontal) sound-velocity gradients. These, in turn, depend on the strength of the thermocline and the angle at which the sound rays intersect it.

Sound rays directed normal to an undulating thermocline intersect it at different angles. The refraction and sound-focusing effects can be calculated by applying Snell's Law. This was done, using a Univac computer. The calculations were based on a common transducer pattern and the normal velocity structure observed at the tower during summer. This structure is a mixed layer for the upper 30 feet: a thermocline of -4.8 ft

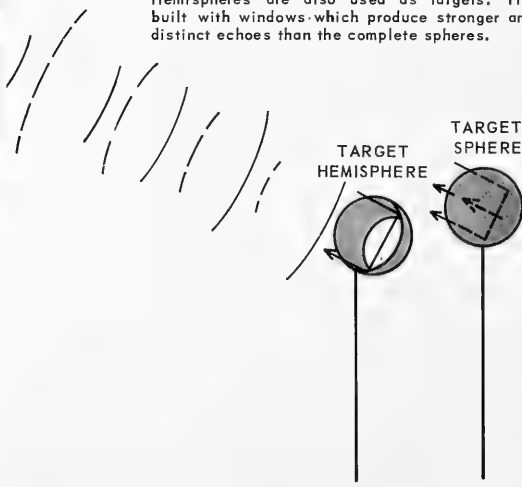


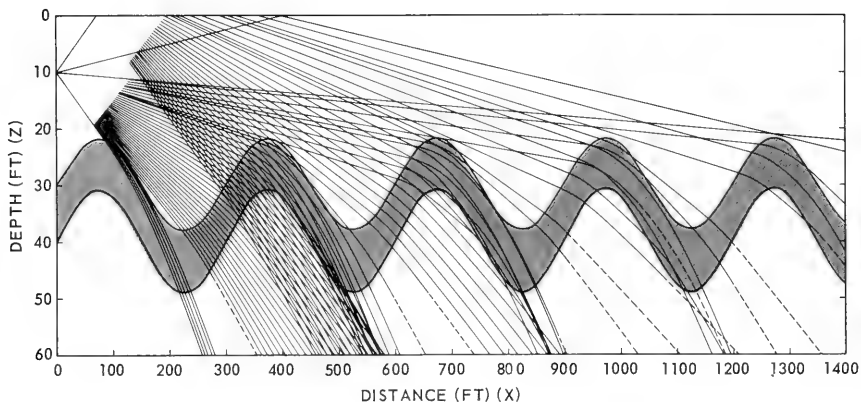
$\text{sec}^{-1} \text{ ft}^{-1}$ for 10 feet; and a deeper 20-foot layer of $-0.6 \text{ ft sec}^{-1} \text{ ft}^{-1}$.

The internal wave had a normal amplitude of -9 feet and a wave length of 300 feet. The focusing effects computed by the Univac were later verified experimentally at the tower.

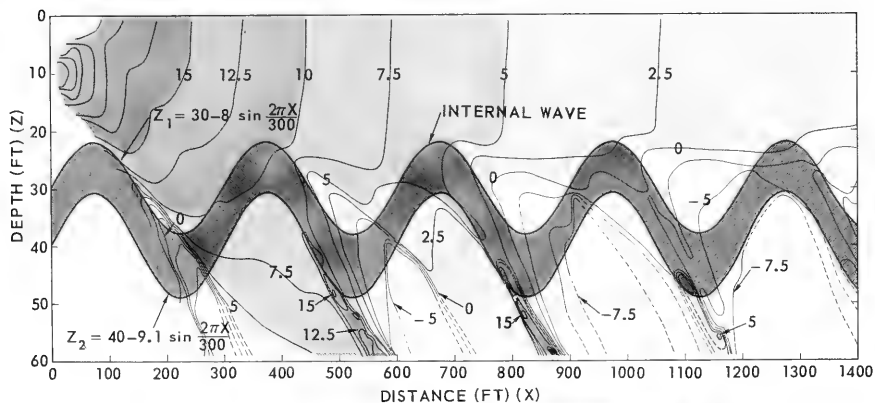


One and two-way sound transmission studies are conducted with a 175-kc/s sonar transducer mounted on the west track at varying depths below the surface. The orientation and depth of the transducer are maintained by the rigid tracks. Signals are transmitted through internal waves to hydrophones and acoustic targets consisting of 1-foot-diameter aluminum spheres, buoyed 7 feet from the sea floor. Hemispheres are also used as targets. They are built with windows which produce stronger and more distinct echoes than the complete spheres.

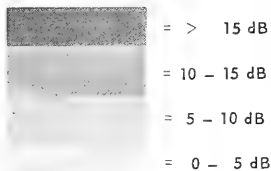




The rays from a directional transducer (1/10 full strength at ± 8 degrees) mounted 10 feet below the sea surface will refract when passing through the average summer internal wave structure. The refraction depends upon the angle of approach of the sound rays. Note how the ray paths converge and diverge as a result of the internal wave effects.



Above the thermocline the sound-level intensity decreases approximately as the square of the distance, but below the thermocline there are regions of high and low intensity. As the internal wave proceeds past the tower the zones of high and low intensity move in accordance with the refraction pattern. The dB values given refer to a sound level of 60 dB 1 foot from the directional source.

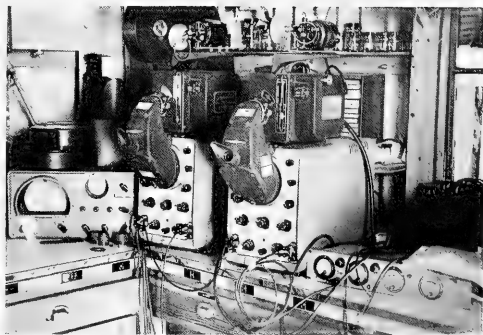


SOUND TRANSMISSION (Continued)

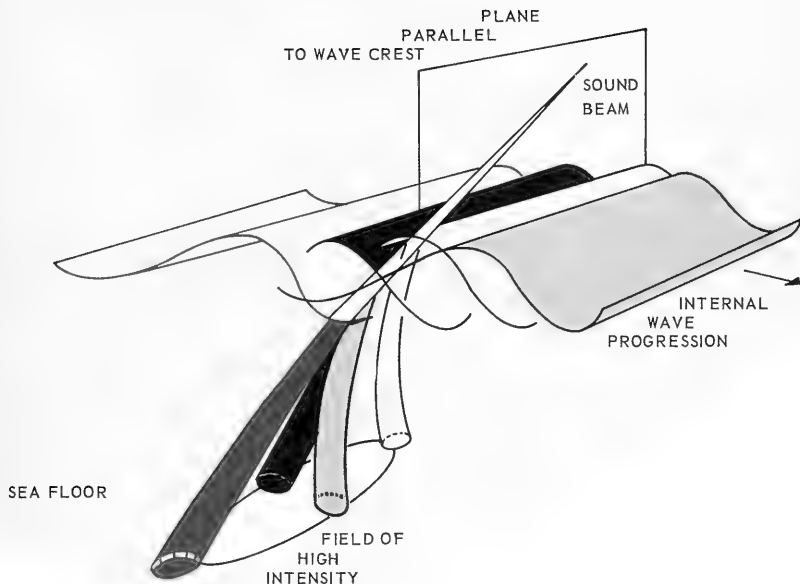
Sound rays directed at other than normal angles to an undulating thermocline are refracted both horizontally and vertically.

In one series of tests a high-frequency, tower-mounted transducer was trained on target spheres tethered 7 feet above the bottom 100 feet from the tower. One target was located southwest, another to the west, and another to the north of the tower. The amplitude of the return ping as a function of time was recorded simultaneously with, and independently of, the internal waves. The sound record shows fluctuations in transmission of up to 30 dB. An analysis of the internal-wave and sound-transmission spectra revealed that the two are frequency-coupled at the fundamental frequency, but that the higher harmonics must be considered when comparing the simultaneous spectra of internal waves with the sound level.

Results also indicate that changes in the relative angle between sound beams are reflected in the intensity and character of reflected signals. Internal-wave characteristics are of the utmost importance in the operational and experimental use of underwater sound.

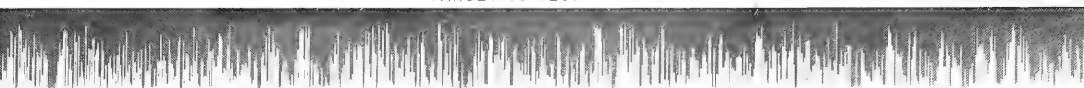


Amplitude of a transducer's return ping as a function of time is displayed on a scope and recorded on 35-mm film by the sonar receiver. Analysis reveals the pattern of focusing and defocusing of sound rays caused by internal waves.

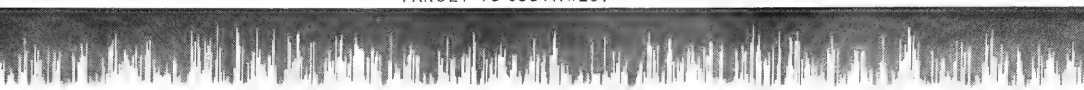


As the sound beam is directed through internal waves in a direction parallel to their crests, it is refracted both horizontally and vertically by the moving thermocline. As a result, the higher intensity cones of sound tend to subscribe an ellipse on the sea floor with each passing internal wave.

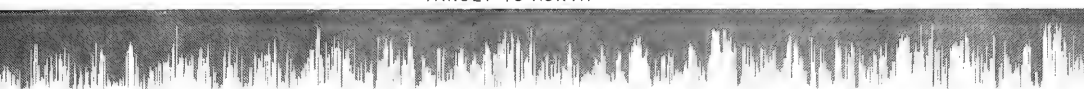
TARGET TO WEST



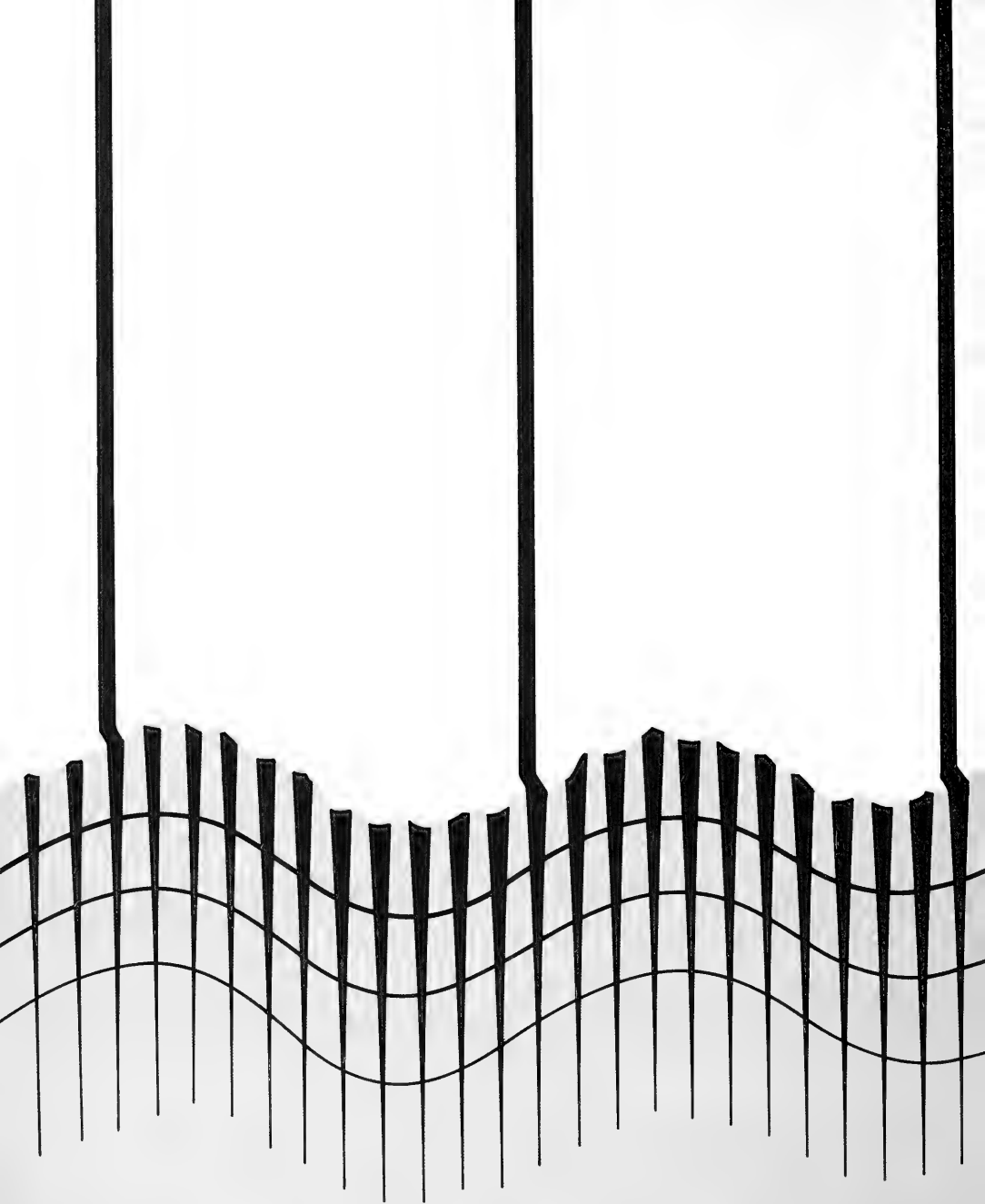
TARGET TO SOUTHWEST



TARGET TO NORTH



Typical sonar transmission recordings in three directions show short-period (less than 1-second) changes in sound-reflection intensity. Some larger intensity changes occur within several seconds; others, related to the character of internal waves, have periods of around 7 to 10 minutes and show fluctuations of as much as 30 dB. Sound rays traveling parallel or nearly parallel to internal wave crests (to N) show greater variation in intensity than do sound rays traveling at right angles to internal wave crests.



ELECTROMAGNETIC WAVE PROPAGATION STUDIES

The propagation and reception of very low frequency (vlf) electromagnetic waves underwater have been investigated utilizing the tower's vertical railway system to achieve preselected depths.

Measurements of subsurface signal attenuation made during this period revealed that the tower structure has a negligible effect on wave reception to a depth of 35 feet. The tower also provided the requirements of open-sea, natural-wave conditions and unsheltered exposure. An additional advantage was the tower's stability, which permitted the collection of more data at less cost than could have been obtained by use of a relatively unstable submersible.



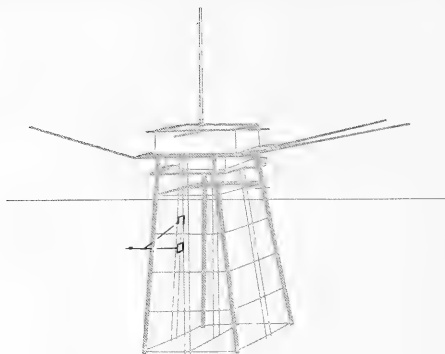
VLF Transmission

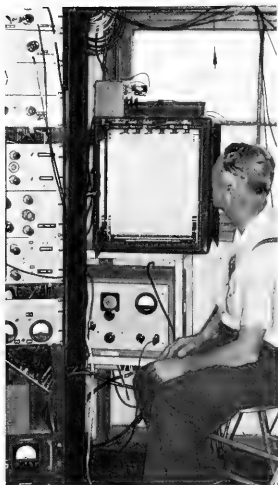
VLF Transmission

Undersea reception of very low frequency signals suffers from large amplitude attenuation and severe phase perturbations. The latter result from waves which cause variations in the distance from the sea surface to the point of reception. Experiments utilizing a frequency of 17.2 kc/s show that the change in phase amounts to 8.2 degrees per foot of sea water path. This is of major concern in a phase-coherent signaling system. Signal attenuation, on the order of 1.3 dB per foot of immersion, is also observed.

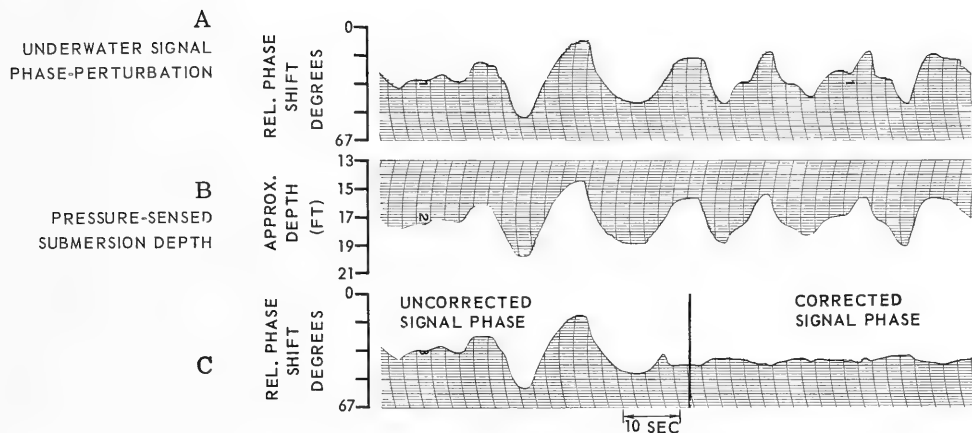
Studies at the tower are aimed at establishing adequate control for a phase-compensating system. Pressure measurements are made which are known to correlate with the length of the subsurface transmission path. Other factors such as temperature, salinity, antenna orientation, antenna motion, and the relative orientation of water wave to electromagnetic wave are also related to the overall problem of vlf propagation.

An underwater-loop antenna and pressure transducer are extended 12 feet out from the tower rail before being lowered to varying depths for studies of transmission. With the subsurface wooden extensions, the tower had negligible effect on vlf attenuation measurements down to a depth of 35 feet (over half-way to the bottom).





A scientist simultaneously records vlf signals underwater and above the surface. The continuous 17.2-kc/s unmodulated signals were received from Chollas Heights Navy Transmitter approximately 13 miles distant. A phase comparator produces dc signals representing the relative phase of "air" and "underwater" signals, which is charted as the "uncorrected phase." The vlf underwater signal is electronically modified, by compensating for the changing pressure (depth) caused by sea-surface waves, to give a more constant or corrected signal phase.



Comparison of recorded (A) underwater observed signal phase, (B) pressure at the receiver depth, and (C) the more usable signal phase, corrected for pressure (depth) at the receiver.

CHEMICAL STUDIES

Chemical research at the tower is concerned with several phases of the oceanographic program. Salinity, in conjunction with temperature, is determined for use in computing sound velocity and water density. Oxygen content and foaming properties are studied in connection with sound propagation and attenuation. Plant nutrients are investigated for their influence on phytoplankton production, which largely controls underwater visibility. Radioactivity of marine organisms is studied for biological absorption research.



Salinity

Oxygen

Plant nutrients

Foaming properties

Radioactivity

Salinity and Oxygen

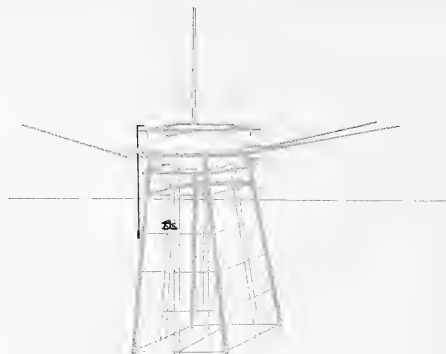
Periodic determinations of salinity throughout the 60-foot water column, made during spring and summer, indicate that there is rarely a variation of over 0.24‰ from the surface to the bottom, and the average maximum vertical range is only 0.19‰. Values are usually higher at the sea floor and decrease towards the surface. However, when stronger summer temperature gradients are present a slight inversion in salinity structure usually occurs.

For the study of internal waves, the vertical density and Väisälä frequency (stability frequency) can be computed from measurements of the salinity and temperature structure.

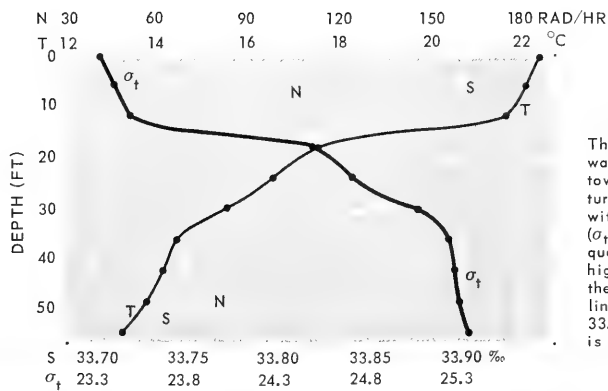
Sea-water samples collected at the tower are analyzed to find dissolved oxygen content. During spring and summer, dissolved oxygen values range between 4 and 8 ml/l. Higher values include oxygen supplied by photosynthetic action.

Oxygen saturation may exceed 100 percent because of biological action and changes in pressure and temperature. In this supersaturated condition, internal waves, turbulent motion, water heating, or the further generation of gas by phytoplankton causes the release of oxygen bubbles. These bubbles rise to the surface or adhere to organisms. They can attenuate underwater sound.

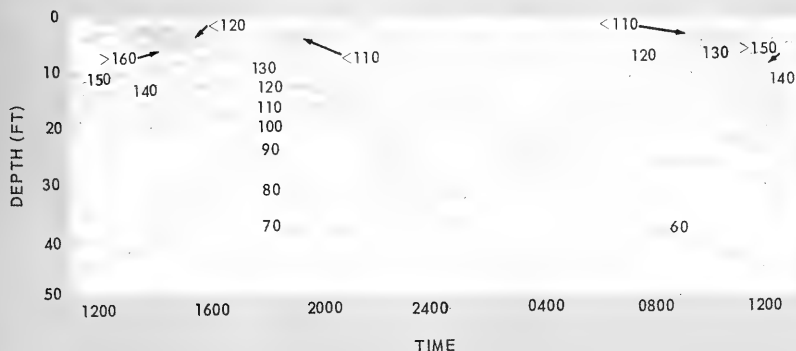
Other studies of gas bubbles in the water were made from samples collected in situ by means of a large suspended inverted funnel. Analyses revealed this gas to be composed of: O_2 14 to 18 percent; CO_2 1 to 2 percent; CO 0 to 1 percent; CH_4 0 to 1 percent; N_2 78 to 85 percent.



To determine salinity, oxygen, and water density, water samples and temperatures are collected with Nansen bottles at intervals from surface to bottom. Water samples, taken during the summer and analyzed with a laboratory salinometer, show nearly uniform values from surface to bottom. For long-period variations in salinity, an *in situ* salinometer is mounted on a tripod out from the tower. Water samples, collected in water bottles, are analyzed for oxygen by the Winkler method.



This graph, based on a series of water samples collected at the tower in summer, shows temperature (T) and salinity (S) decrease with depth, whereas density (σ_t) increases. The Väisälä frequency (N) fluctuates, with the highest values being found in the thermocline. In summer, the salinity ranges from 33.75‰ to 33.96‰. The average year around is 33.60‰.



Graph reveals the percent of oxygen saturation at one atmosphere and observed temperature throughout one day in July. Note that the oxygen saturation of sea water to depths of 20 feet sometimes exceeds 100 percent.

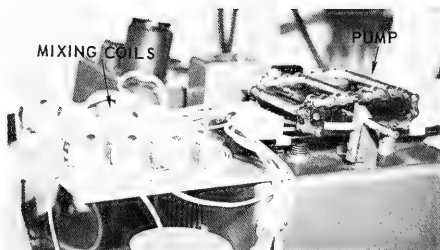
Plant Nutrients

Plant nutrients, together with sunlight, facilitate organic production, especially that of phytoplankton. This lowers visibility underwater.

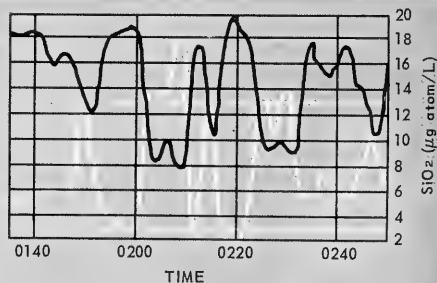
At the tower, the plant nutrient concentrations are determined with an Auto Analyzer. This apparatus mechanically mixes the sea water sample with chemical reagents and introduces the mixture into a continuously recording colorimeter. The various plant nutrients such as phosphate, silicate, and nitrate have been continuously recorded with respect to both space and time. Silicon was determined by a modification of a molybdenum blue method, using stannous chloride as a reductant; nitrate was determined by reduction to nitrite with a copper-cadmium couple, followed by an adaptation of a standard nitrite determination.

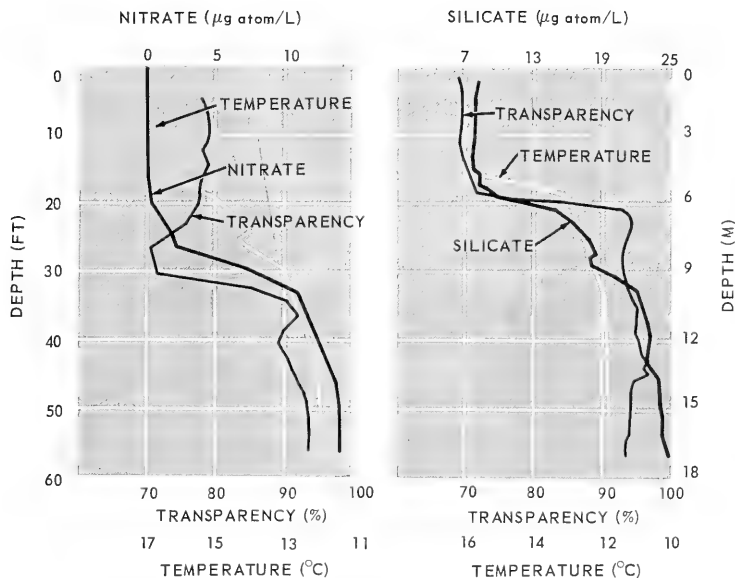
At the shallow-water tower site, the nitrate and silicate recordings in the vertical water column vary widely. In spring, the nutrient content in the upper layer of the sea is normally low. A strong thermocline separates this layer from the high values in the deeper layer.

A continuous recording at a constant depth (30 feet) from the bottom shows the changes in temperature and concentration of silicate caused by internal waves as they move the nutrient boundary vertically past the sampling level.

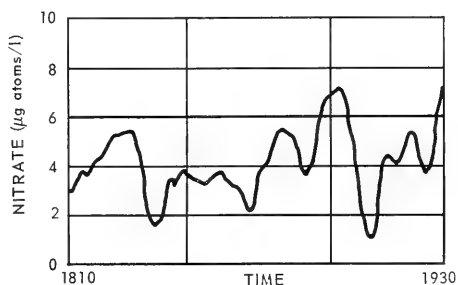
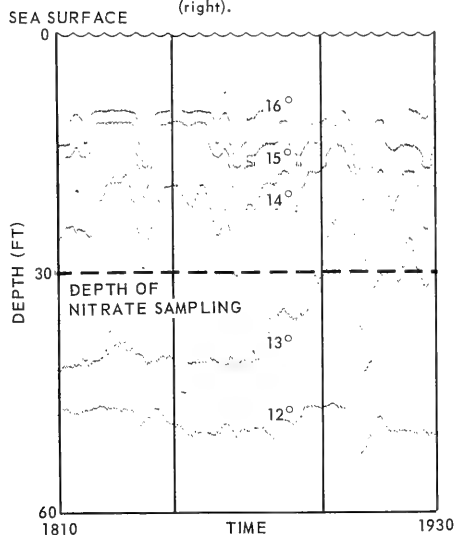


A continuous supply of sea water from the submersible pump on the north track is automatically mixed with reagents by an Auto Analyzer proportioning pump and fed into the colorimeter.





Simultaneous nitrate, water transparency, and temperature records (left) show abrupt changes at the same depth. At this level and above, the low transparency water has a decreased nutrient concentration, since the nitrate has been used up by plankton. A similar abrupt change may be observed in the water transparency, temperature, and silicate relationship (right).



Nitrate values rise and fall in direct relation to the oscillation of an internal wave (in the thermocline). Whenever the thermocline barrier is raised to or near the surface by upwelling or large internal waves, the deeper, colder water, which contains a higher concentration of nitrate, may induce plankton blooms to occur. The nitrate values (right) were recorded at 30 feet simultaneously with temperature (left).

Foaming Properties

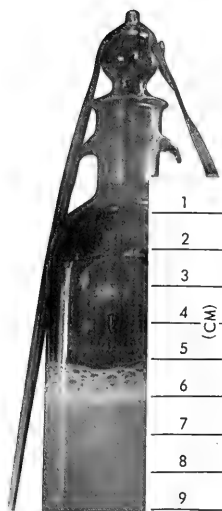
The ability of sea water to produce and maintain bubbles can be measured through a study of foaming properties. The tower's site enables foam to be collected for immediate analysis.

Foam is concentrated by the convergence circulation created by internal waves - the foam persists longer in slicks because the accumulated organic film reduces the surface tension.

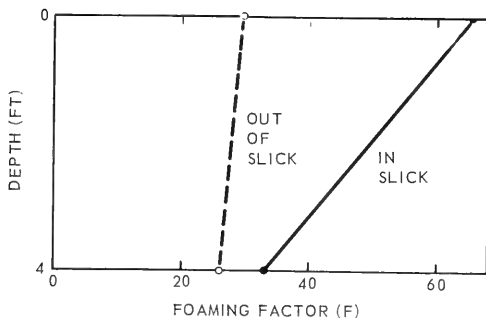
Samples of water collected adjacent to and beneath sea surface slicks are studied. The samples are shaken to produce foam and then photographed at short intervals. The photographs establish the size of bubbles in the foam; the maximum foam height, H_0 ; and the half-life, or time required for the foam layer to decrease to half its height, T . The product $H_0 T$ is called the foaming factor, (F) , which is useful in characterizing water types.



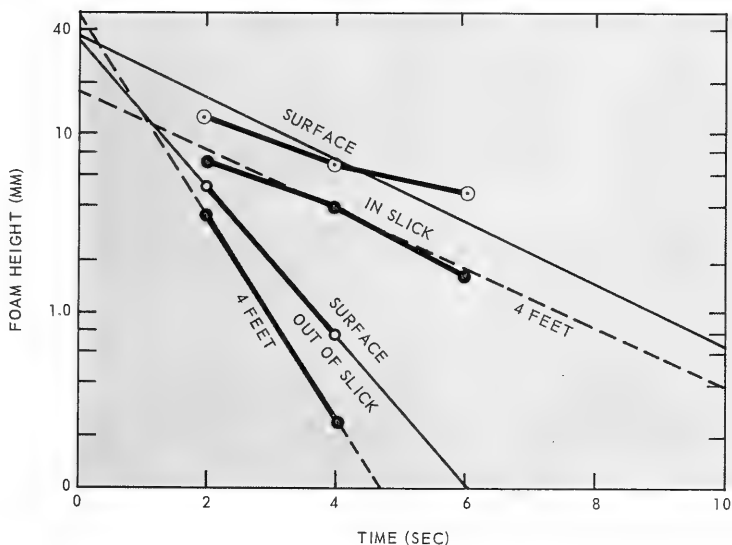
Foam occurs naturally in the sea as a result of strong winds, ship wakes, or breaking waves (white caps). It may persist from 4 to 20 seconds, depending on the foaming factor of the water.



Sea-water samples collected adjacent to and beneath slicks are shaken at known speed and time. After this, the foam layer is photographed every 2 seconds. The initial mean diameter of bubbles in a normal foam layer is about 0.5 mm. This diameter increases to around 0.8 mm after 10 seconds due to coalescence. The mean maximum diameter increases from 1.8 to 2.7 mm in the same time interval.



Water samples collected in slick areas produce higher foaming factor values than samples collected from outside the convergence area under slicks. These samples were collected from near and 4 feet below the surface during July.

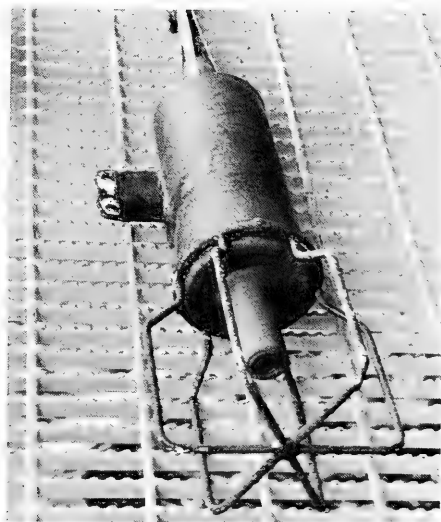
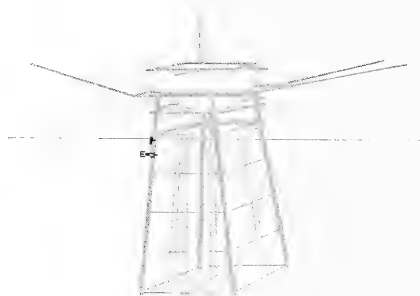


Foam produced in water collected outside slicks decays three times as rapidly as foam from nearby slick areas. This indicates that water in and under the slick zone contains more organic material, has a higher foaming factor, and produces more stable foam.

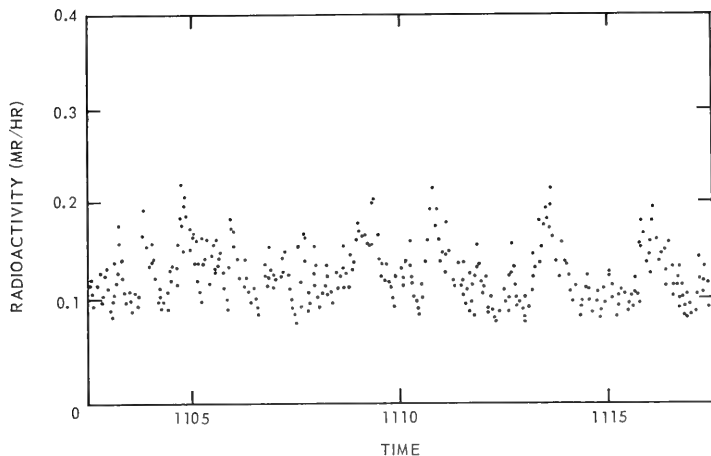
Radioactivity

Continuous monitoring of sea water for gamma rays is carried out with a scintillation meter system to establish a background level and to relate any changes to biological or other causes. The background is normally very low, running 0.007 to 0.017 mR/hr. This level is maintained for long periods of time. However, occasional increases in radioactivity over normal background have been observed, especially in summer.

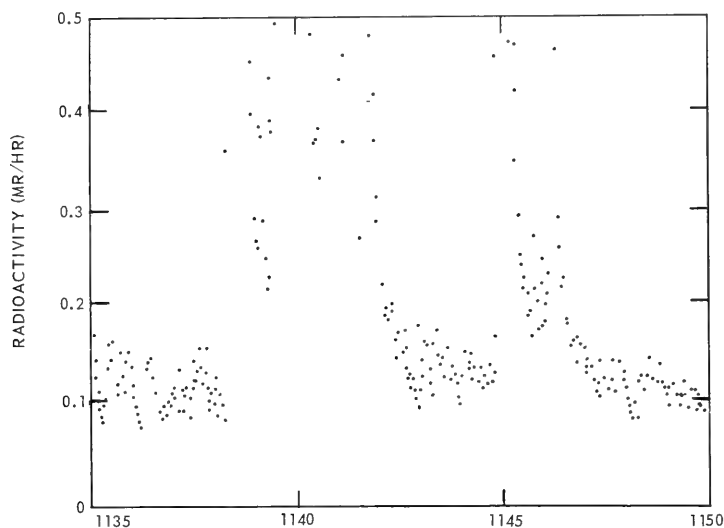
Further investigation correlated this significant intensification in radiation with occasional blooming of the phytoplankton *Gonyaulax polyedra*. Thus, increased radioactivity can usually be correlated with high water turbidity.



Heart of the radiation detection system is this gamma ray sensor, mounted 10 feet below mean tide level. Amplified signals of radiation intensity are transmitted through electric cables to a recorder in the instrument house. Instrumentation sensitivity ranges are 0 to 0.05, 0 to 0.5, 0 to 5.0, and 0 to 500 mR/hr. Because of the normally low background count, the recorder is usually set on the 0- to 0.5-mR/hr scale.

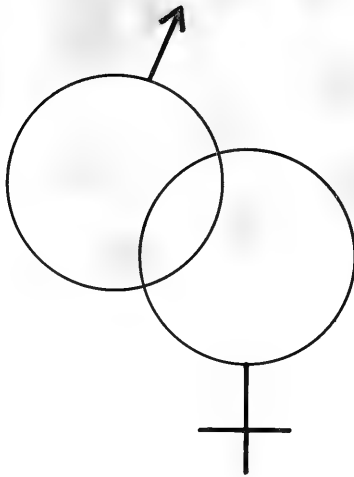


A strip-chart recording of the normal background radiation count shows small oscillations (0.01 mR/hr), and wave periods of about 2 minutes. Normal background count fluctuates between 0.0007 and 0.017 mR/hr. No appreciable diurnal nor tidal cycle variation in radioactivity has been detected.



Gonyaulax polyedra

As the patches of *Gonyaulax polyedra* pass the sensor unit during a "red tide," readings of 2.0, 3.5, 5.0, and in some instances greater than 5.0 mR/hr have been observed. They last from 1 to 10 minutes. The high count is attributed to the apparent ability of certain phytoplankton to concentrate radioactive phosphorus from sea water. The highest rises in radioactivity occur in the summer.



BIOLOGICAL STUDIES

The abundance of shallow and (in some seasons) deep-water fauna and flora around the tower offers an ideal opportunity for systematic investigation of biological organisms related to under-sea problems.

Studies of marine plants and animals living on and adjacent to the tower cover a wide range, from fouling to feeding habits. The examples presented here are concerned with plankton and its effect on water turbidity, and with the vertical and horizontal distribution of fish that reflect acoustic waves.

Water turbidity

Plankton distribution

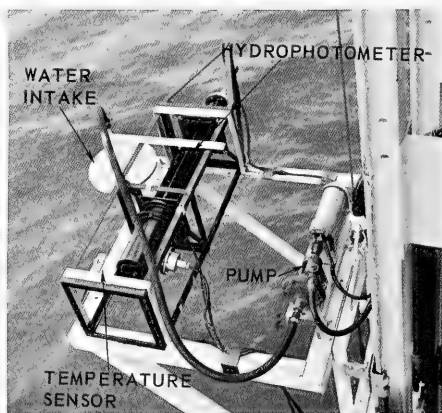
Fish distribution

Water Turbidity

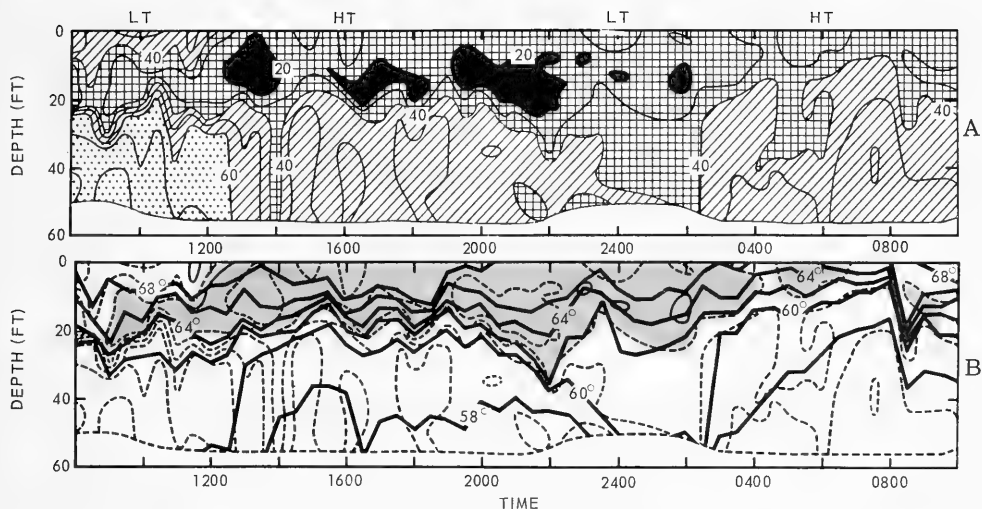
Summer studies of the transparency of water adjacent to the tower have been made using a hydrophotometer. The studies record light-transmission values ranging from 20 to 80 percent, based on a distilled water standard of 100 percent. Throughout the winter months the clearer water readings approach 100 percent.

Water turbidity is caused by inorganic, dissolved matter and various forms of biological material. However, most turbidity in the water column is related to the phytoplankton population. During summer, plankton blooms frequently develop just below the surface, with a low transparency reading (less than 20 percent). Patchiness is caused in part by vertical circulation which brings clearer water upward, creating zones of high transparency within the general turbid region. Following the heavy surface blooms, the lower levels of the water column become more turbid and the upper level clears.

The area of maximum turbidity frequently coincides with the maximum vertical thermal gradient. Because the thermocline oscillates vertically with internal waves, the associated turbid layer also oscillates. In some cases, water visibility changes with the tide, with periods of high waves, and with vertical or horizontal water mass boundaries. As irregular turbid zones move past the tower, changes in light transmission as great as 50 percent may occur in 2 minutes.

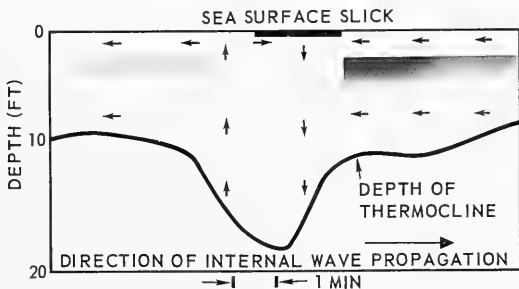


Water transparency is determined by a hydrophotometer (alpha meter). The device measures light scattering and absorption by particles in the water at varying levels. Temperature and biological specimens are taken concurrently and at the same level.



Sample time-depth plots of water transparency at the tower during a 27-hour period show (A) the early stages of a *Gonyaulax* plankton bloom with maximum concentration just below the surface, and (B) the corresponding water temperature structure (heavy lines) in degrees F. Transparency less than 30 percent is grey. The greatest plankton concentration occurs at the level of maximum temperature gradient.

Red water with maximum turbidity slightly below the surface is separated by bands of relatively clear water beneath the sea-surface slick. This patchiness in turbidity is caused by vertical currents associated with a passing internal wave.



Plankton Distribution

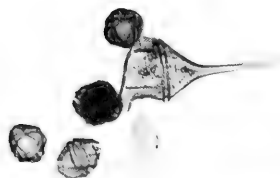
The water at the tower contains numerous species of both phyto- and zooplankton, but frequently one organism dominates. During one investigation plankton populations and movements were studied. Over 200 samples were collected at 3-meter intervals throughout the water column. These repeated samplings were made at 2-hour intervals for more than 24 hours.

At this time the main organism in the bloom was a naked dinoflagellate, *Gymnodinium flavum* (yellow water). It was present in concentrations up to 3.2×10^6 cells per liter. The bloom correlated closely in space, time, and intensity with a highly turbid layer (30- to 50-percent transparency), which was resting on a strong thermocline. Pigmented-cell zooplankton and organic detritus, present in significantly lesser volume, showed little correlation with the turbid area. Two weeks later the turbid zone was ill-defined. *Gymnodinium* had abated to maximum concentrations of 4.8×10^3 cells per liter, while another dinoflagellate, *Ceratium*, was associated with patchy turbid areas. However, the most dominant organism in recent years has been *Gonyaulax polyedra*. Thus, the principal organisms causing turbidity differ with time and changing environmental conditions.

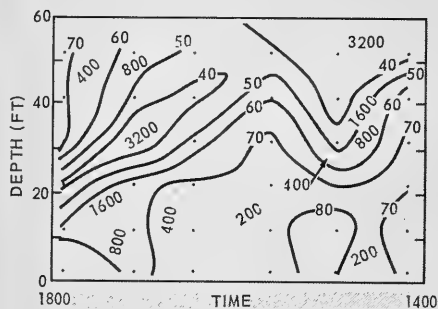


A submersible pump collects planktonic material that causes water turbidity in the tower area. The pump brings fresh sea water by hose from a predetermined (or continuously changing) depth up to a catwalk, where a known volume is filtered with a plankton net.





Other sea-water samples are passed through millipore filters to obtain microscopic organisms. Larger plant and animal plankton, many of which are bioluminescent, are occasionally collected with fine-meshed fishing nets lowered from the tower booms.



A time-depth plot of the observed relationship between the percent water transparency (black lines) and the total count of all plankton organisms (white lines) is shown on this composite chart. Over a period of about a day the depth and time of low water transparency zones closely coincides with that of the high microorganism count.

Fish Distribution

The tower environment attracts and maintains certain varieties of fish.

Studies of fish behavior underneath and adjacent to the structure are facilitated by the remotely monitored and controlled television system attached to the south rail track. The cameras, with their automated pan and tilt mounts, follow both horizontal and vertical animal movements.

A technique and a graphic guide for identification of the fourteen common species of fish viewed on the television monitor have been developed and used successfully. The method utilizes a series of binomial choices based on physical appearance and movement. For example, a fish is initially classified by body shape, then by fin location or swim pattern, and finally by body markings.

Television observations of fish over several days at regular time and depth intervals have revealed:

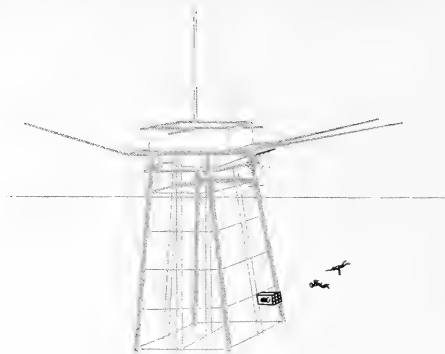
The vertical layering of various species during the day.

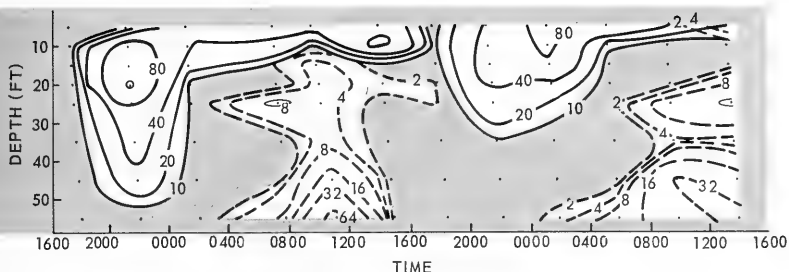
Changes in vertical distribution patterns at night.

Avoidance and attraction of various species by camera lights and TV tilt-train noise.

Changes in schooling and behavior traits at various times of day.

Schools of pelagic mackerel are common visitors around the tower during the winter months but are relatively rare at other times of the year.





Different species of fish have characteristic and predictable time and depth habits. Kelp bass, *Paralabrax Clathratus*, (solid lines) show extensive vertical distribution at night. During the day, however, they remain above the thermocline. (Curves based on 24-hour summer TV observations taken on 2-minute counts at 5-foot intervals throughout the water column.) Pile perch, *Rhacochilus vacca*, (dashed lines) observed over the same period reveal a diurnal distribution opposite to that of kelp bass. The perch show a wide vertical daytime range, although the main population mass remains near the bottom. They are rarely observed during the evening hours.

RESIDENTS (PELAGIC)



HALFMOON

Medialuna californiensis



KELP BASS

Paralabrax clathratus



PILE PERCH

Rhacochilus vacca



BLACK PERCH

Embiotoca jacksoni



STRIPED PERCH

Hypsurus caryi

RESIDENTS (BENTHIC)



KELPFISH

Heterostichus rostratus



CABEZON

Scorpaenichthys marmoratus



SCULPIN

Scorpaena guttata



MUSSEL BLENNY

Hypsoblennius

VISITORS (PELAGIC)



SHINER SEAPERCH

Cymatogaster aggregata



SAND BASS

Paralabrax nebulifer



WHITE SEA PERCH

Phanerodon furcatus



CALIFORNIA SARCO

Anisotremus davidsonii

VISITORS (BENTHIC)



SHEEP-HEAD

Pimelometopon pulchrum



LEFTEYED FLOUNDER

Bothidae



GOPHER ROCKFISH

Sebastes carnatus

Some species of fish are permanent residents around the tower while others are occasional visitors.



GEOLOGICAL STUDIES

Geological investigations from the tower utilize the underwater TV system as well as scuba and hookah diving equipment for *in situ* sea-floor observations and samplings. General topography, microrelief, subsurface structure, sediment distribution, and associated erosional and depositional process studies are carried out in support of acoustic and bottom stability research.

In addition to employment of scuba and hookah for *in situ* work, the Cousteau diving saucer SP 300 has been used to provide additional information on geological features seaward of the tower. The subbottom was investigated with high-power acoustic reflection equipment and by coring.

Sea-floor topography

Sediment distribution

Subbottom structures

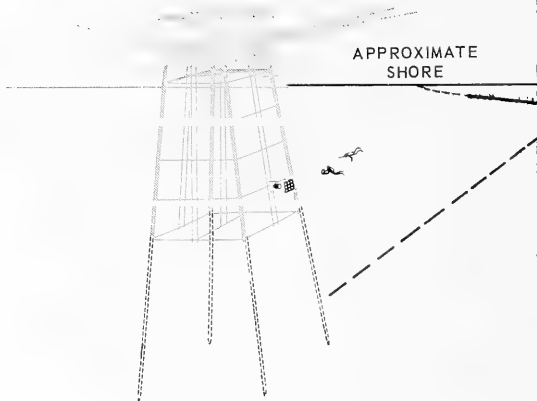
Mine scour

Sea-Floor Topography and Sediment Distribution

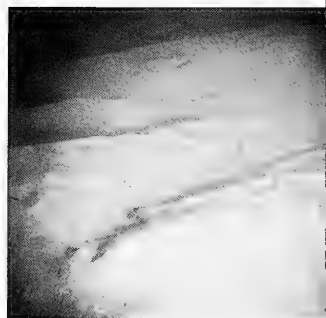
Detailed geological mapping of the sea floor around the tower shows recent marine sands overlying older deltaic sedimentary fill of the San Diego River.

The sea-floor surface from Mission Beach to the tower is composed of well-sorted, fine-grained gray sand, with a median particle diameter of 0.09 millimeter, and ripple marks approximately 3 to 4 inches high. At the tower, sediments change abruptly. Ripple marks increase to an average height of 6 inches, and sand grain size increases to around 0.31 millimeter. About 1 mile west of the tower the bottom sediment again becomes finer, ripple marks disappear, and the bottom slope steepens.

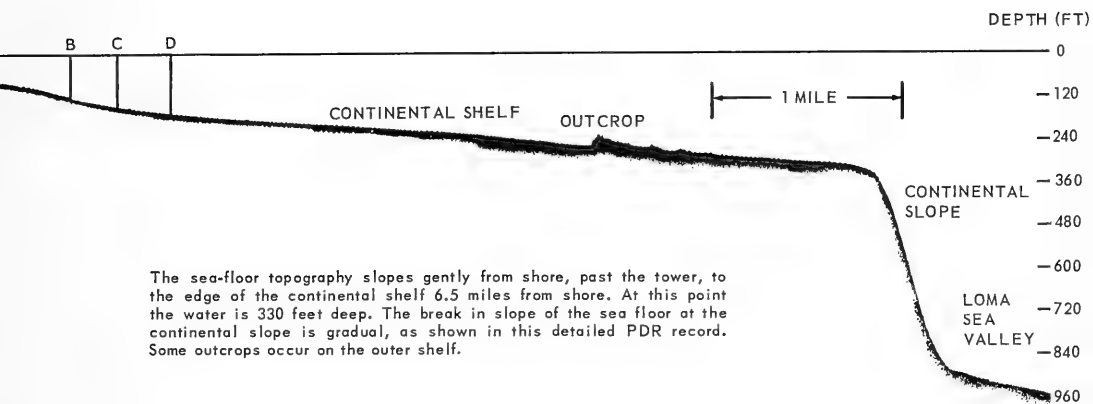
Long-term sea-floor observations around the tower using scuba and television have identified cyclic variations in ripple mark heights corresponding to seasonal variations in waves, currents, and animal populations. In winter, ripple marks reach a height of approximately 8 inches (with wavelengths up to 40 inches). In summer, they gradually reduce to 2 or 3 inches high due to decreasing water motion and increased activity of marine organisms.



A



Some 900 feet west of the tower, at a depth of 66 feet, coarse sand ripples measuring 36 inches from crest to crest are in evidence. Their 6-inch high peaks show irregular erosion by sand dollars, heart urchins, and sea urchins. Scattered broken shells and a thin layer of organic matter have collected in the troughs.



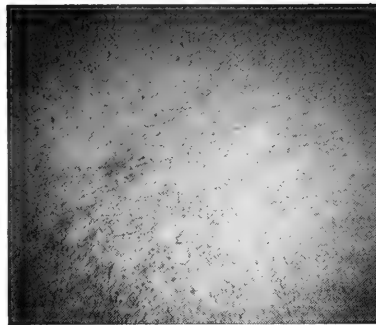
B



C



D



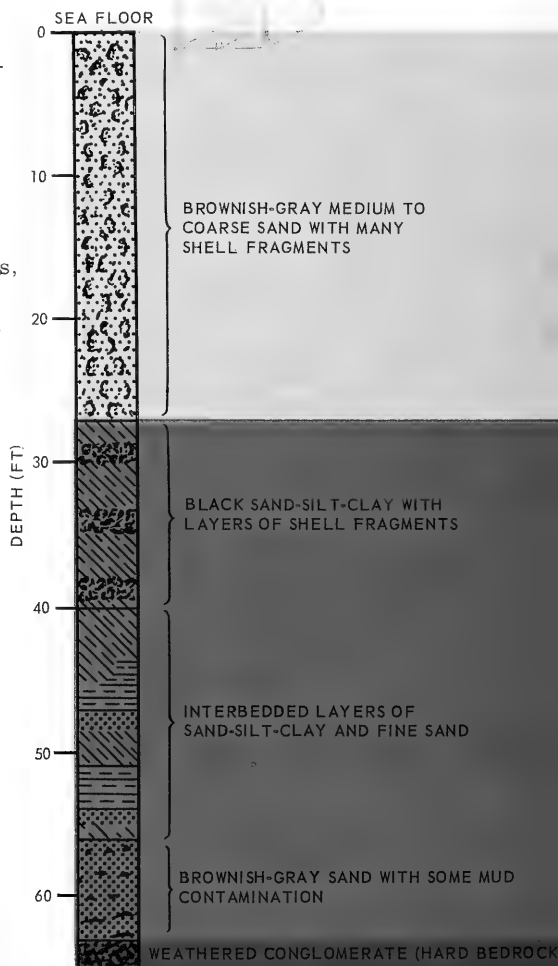
Proceeding west a distance of 4400 feet from the tower at a depth of 100 feet, there are sharp-crested medium sand ripples 24 inches long and 5 inches high.

Medium sand ripples give way 5300 feet out to 1-inch high rounded ripples composed of fine sand. Depth here is 128 feet. Organic matter, forming a thin layer on the surface, is again noticeable.

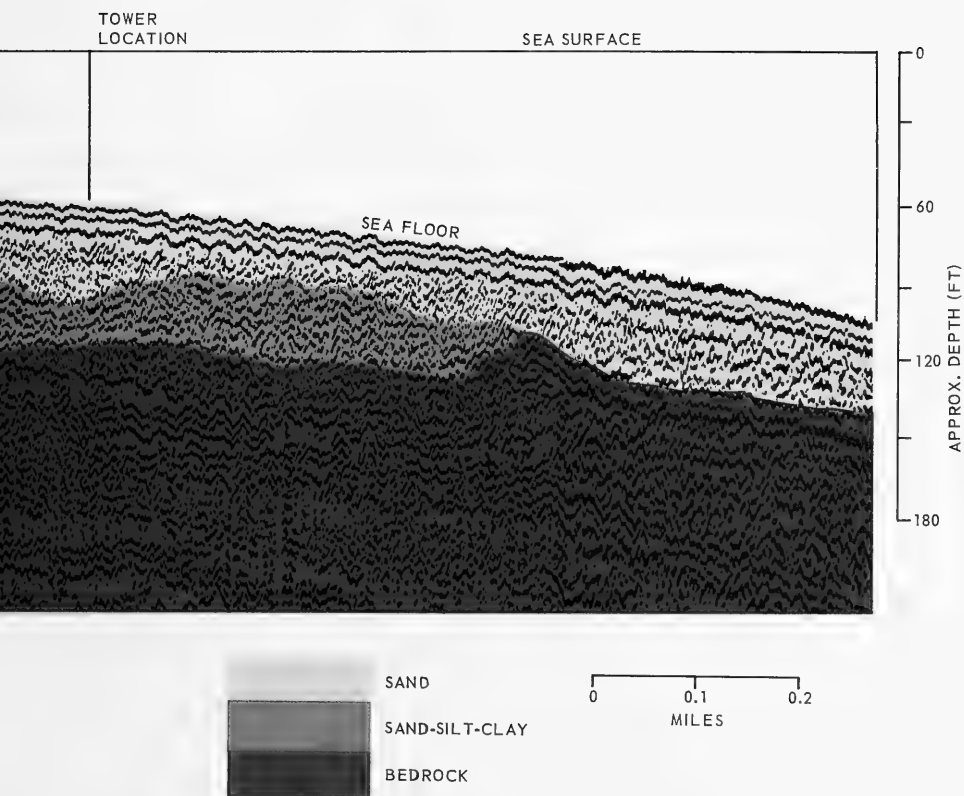
Gradation of the fine sand ripples into fine silt takes place 7000 feet from the tower in water 164 deep. The smooth bottom, pockmarked with occasional small depressions, is also mantled with organic detritus.

Subbottom Structure

Information on subbottom structure near the tower site and along a traverse from near shore to approximately a mile and a half seaward of the tower was obtained. This was done by using a continuous reflection profiler with a pneumatic acoustic repeating source fired at a rapid rate ($1/4$ of a second) and a high-resolution graphic recorder. The reflection of the transmitted sound is the result of sound velocity, density, and porosity contrasts along subbottom stratified layers or surfaces of unconformity. These reflections may be interpreted as lithologic or structural units, and, with the aid of core samples, may be correlated with actual sediment units.



Prior to the installations of the tower, a core boring was made at the proposed site which shows unconsolidated sedimentary layers to 63 feet. Superimposed color shows the close relation of core hole data and the sub-bottom structure as defined from later acoustic reflection profiles.



This reflection profile shows an erosional bedrock surface (dark green) situated about 60 feet beneath the sea floor at the tower. This surface slopes gently seaward with a subbottom high approximately 1/2 mile west of the tower. The bedrock is probably cretaceous sandstone, conglomerates, and shales like those cropping out on nearby Point Loma. The records show deep reflecting structures, indicating that the bedding is nearly horizontal in the vicinity of the tower. Overlying the bedrock is sand-silt-clay (loam) 30 to 70 feet thick. This section has layers of shells interbedded with sandier zones, which probably represents an ancient low sea level deltaic or bay deposit. Overlying this section of ancient bay or deltaic deposits of the San Diego River is a zone of transgressive marine sands (light green). This occurred during the Holocene period as the glaciers melted. The uppermost parts have been modified by present-day currents and wave action. In the subbottom profile (above) the depth to subbottom reflectors is approximate due to variations in sound travel time through sediments.

MINE SCOUR

Some effects of current-borne sediments and bottom erosion on objects on the sea floor have been determined through the use of plaster-filled mine cases. One case was placed on the bottom 8 feet from the tower and oriented in an east-west direction. Later, another case was placed on the bottom and oriented north-south.

Continued observation by television and scuba disclosed any movement or burial of the mines. For the mine with the north-south oriented position the on-shore, off-shore surge was restricted around the obstruction. An anaerobic area developed on the sea floor, with worm tubes projecting from the black subsurface sediment.



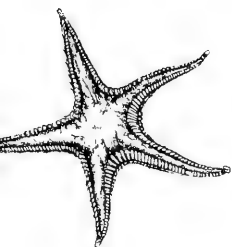
WHITE SEA URCHIN
Hytechinus anamesus



HEART URCHIN
Lovenia cordiformis

Divers made repeated visual inspections and measurements of the environment around the mines. (A) During winter, large sand ripples were observed moving shoreward past the mine cases. Ripple crests tended to orient parallel to the north-south mine case and to incorporate the case within the ripple symmetry. (B) Initially, the white cases were coded with stripes. Within 2 months the epoxy paint became fouled with algae and small balanoid barnacles. (C) The small, white sea urchin, *Hytechinus anamesus*, migrated periodically through the area and covered the cases for several days each time. Spiny sand star, *Astropecten armatus*, attached to the casings. The heart urchin, *Lovenia cordiformis*, was found burrowing and feeding in adjacent sand ripples.

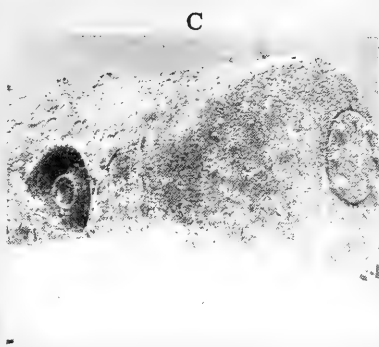
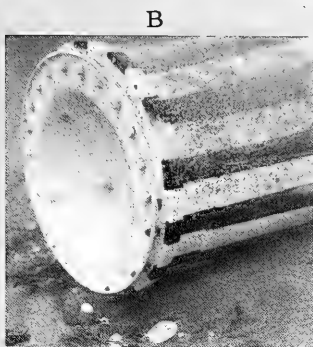


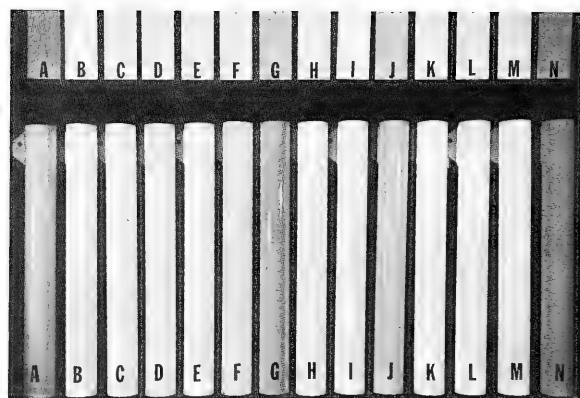


SPINY SAND STAR
Astropecten armatus



Divers inspect scour and fouling of mine case. Note fish and broken shell on sea floor.





MATERIALS RESEARCH STUDIES

The tower is used for materials research studies in such fields as:

Organic coatings

(organic resins, acrylics, vinyls, epoxies, polyurethanes, etc.)

Surface treatments

(anodizing or alodizing of aluminum, HAE or Dow 17 for magnesium alloys)

Cathodic protection

Metal alloys

(nickel or cupronickel)

Antifouling techniques and toxicants

(organometallic compounds, tinbutyltinoxide, chlorination)

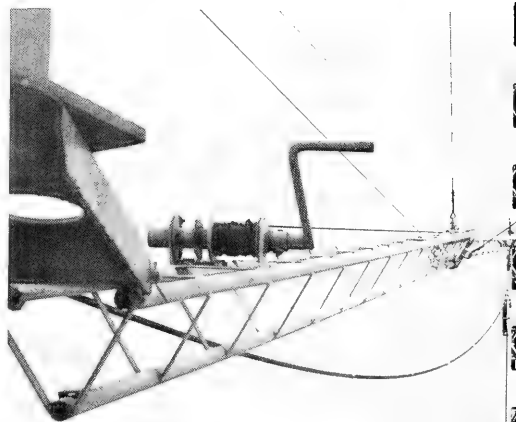
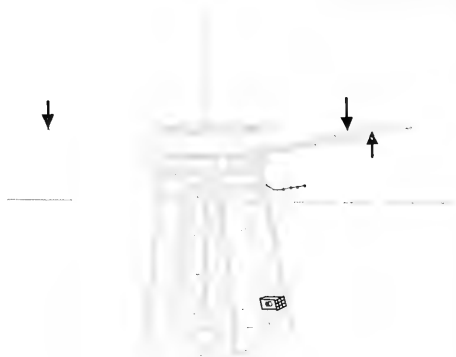
Phosphorescent and fluorescent coatings of different colors were tested on the tower under varied lighting conditions. The fluorescent yellow and red colors (F and G) were more visible against the sea during the day and the bright blue coatings (H, I, L and M) Shannon No. 20 or 22 were more effective at night.

Because much Navy equipment (including hydrophones) must be submerged in the sea for long periods, the protection of materials from corrosion and fouling has grown increasingly critical. The tower offers a favorable site for studies in these fields.

Samples of materials have been placed underwater on the tower and inspected periodically by divers. This work has been supplemented by research on materials suspended in the bay and on racks in a salt-air environment.



Syntactic foam spheres were tested at the tower as instrumentation floats. Alternate floats were coated with a silicone coating (RTV 60) which reduced the marine growth.



Booms and above-water metal structures were test-coated with a polyurethane (Laminar X500) which resists corrosion from salt air for a 5-year period.



Epoxy resin (EPON) was experimentally applied in the intertidal and splash zones (-2.5 to 14.5 feet) to test its effectiveness in preserving the tower from corrosion and fouling. Here a diver pours water over the dry pilings (dolphins) before applying the EPON coating.



Instrument cables are periodically examined and tested for corrosion. A urethane coating has proved useful in preventing corrosion and fouling of running and bearing surfaces in and out of the water.



STUDIES WITH THE DIVING SAUCER

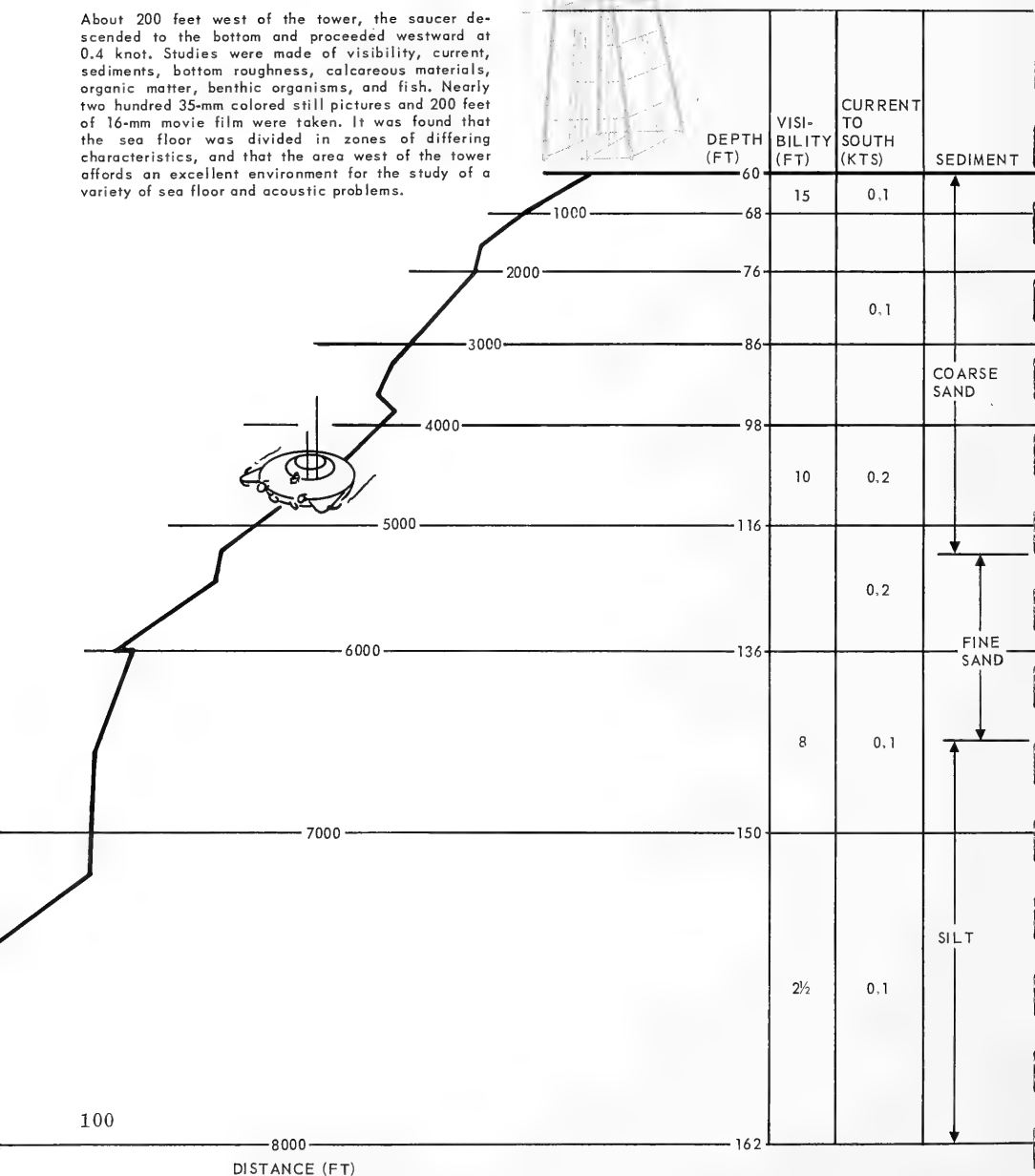
A new research technique developed at NEL consisted of simultaneous investigations from the Cousteau diving saucer and at the tower. This technique extended geographically the area available for oceanographic research. Joint tower-saucer studies included current speed and direction, water transparency, and temperature.

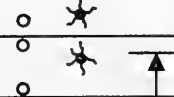

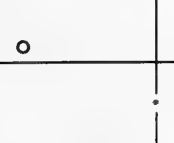


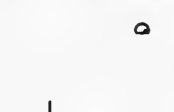


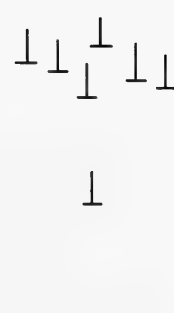


Another purpose of the tower-saucer work was to study the sea floor westward of the tower. The detailed features observed and photographed were sediments, bottom roughness, shell distribution, organic matter, benthic organisms, and fish in the water column and on the sea floor. Each of these factors has an influence on acoustic reflection.

It was also desirable to find out if there were any unusual features which would influence internal waves propagating shoreward up the shelf. Finally, a search was made to determine whether or not the location was suitable for the installation of acoustic arrays and a new tower. It was found to be excellently suited for additional installations.

Tower-saucer joint operations proved highly successful. They extended oceanographic investigations outward from the tower and showed that the area to the west was well suited for additional installations.

About 200 feet west of the tower, the saucer descended to the bottom and proceeded westward at 0.4 knot. Studies were made of visibility, current, sediments, bottom roughness, calcareous materials, organic matter, benthic organisms, and fish. Nearly two hundred 35-mm colored still pictures and 200 feet of 16-mm movie film were taken. It was found that the sea floor was divided in zones of differing characteristics, and that the area west of the tower affords an excellent environment for the study of a variety of sea floor and acoustic problems.



<p>BOTTOM ROUGH- NESS</p>	<p>CALCAREOUS MATERIAL (SHELL)</p>	<p>ORGANIC MATTER</p>	<p>BENTHIC ORGANISMS</p> <ul style="list-style-type: none"> ↓ SEA PEN ○ SAND DOLLAR ✕ BRITTLE STAR • SEA URCHINS ◻ GASTROPODS 	<p>FISH</p>
<p>↑ LARGE RIPPLES (CRESTS ERODED) ↓</p>	<p>↑ SCATTERED, BROKEN ↓</p>	<p>↑ SMALL AMT. IN TROUGHS ↓</p>		
<p>↓ (CRESTS PARTLY ERODED) ↑</p>		<p>↓ LITTLE OR NONE ↑</p>		
<p>↑ (SHARP CREST) ↓</p>	<p>↑ SCATTERED ↓</p>	<p>↓ THIN LAYER ↑</p>		<p>FLOUNDER</p>
<p>↓ (LOW, SMOOTH) ↑</p>	<p>↑ ↓</p>	<p>↓ THIN LAYER ↑</p>		
<p>↓ (SHARPEST) ↑</p>	<p>↑ ↓</p>	<p>↓ THIN LAYER ↑</p>		<p>SURF PERCH</p> 
<p>↓ NEARLY FLAT BOTTOM (WITH OCCASIONAL FISH DEPRES- SIONS) ↑</p>	<p>↑ ↓ VIRTUALLY NONE</p>	<p>↓ THICK LAYER ↑</p>		<p>ANCHOVIES</p>  <p>PILE PERCH</p> 



SERVICE TO OTHER ORGANIZATIONS

In its continuing effort to be of assistance to other naval organizations and Government agencies working on related ocean problems, NEL encourages the use (as time and space permit) of tower facilities and equipment. The following activities have used the tower:

Tower leg brackets constructed and installed for the testing of radioactive materials. The tests were conducted for the Naval Radiological Defense Laboratory, San Francisco, as an inter-laboratory assistance project.

Naval Radiological Defense Laboratory

Effect of open-sea environment on radioactive samples

Navy Antisubmarine Warfare School

Testing and evaluation of sonar transducers

Navy Postgraduate School

High-frequency sonar research

Naval Research Laboratory

Study of sea-slick surface film

Contractors of the Bureau of Ships

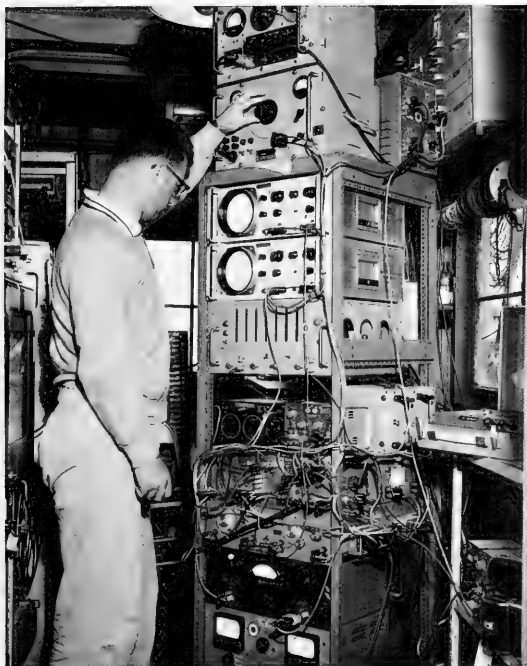
Buoy and equipment tests

U. S. Fish and Wild Life Service

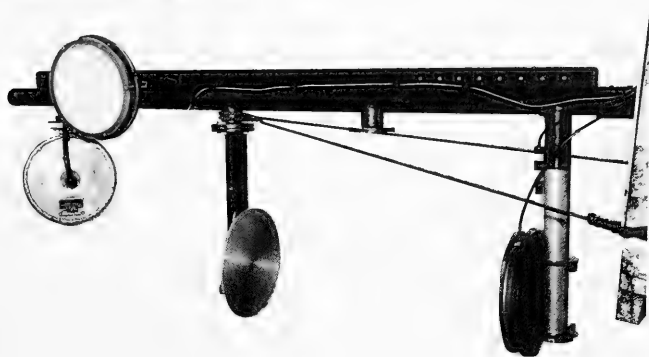
Infrared aerial surveys

Navy Radiological Defense Laboratory experiments showed that specimens of strontium titanate containing trace quantities of strontium 85 yielded low amounts of radio-strontium after having been immersed in sea water. The specimens were mounted in special holders on the tower legs.

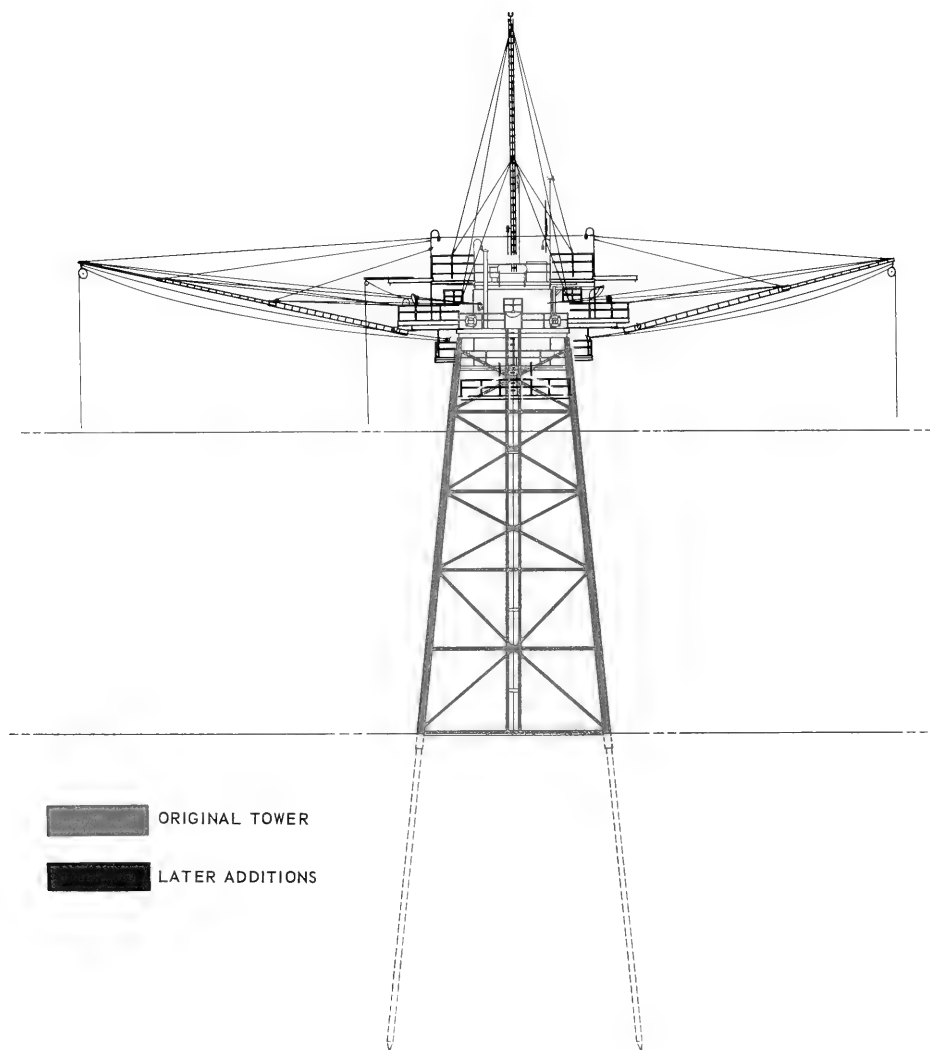




Research in acoustic scattering was carried out at the tower by officer students of the Navy Postgraduate School, Monterey. Measurements at varying depths, frequencies, and times provided data on the size and distribution of scattering particles in the water. These data were used for thesis material.



Postgraduate School students employed a variable-depth electrostatic transducer which transmitted signals over a 3-octave band (24 to 192 kc/s). It determined the presence and distribution of scatterers in the water column.



PART III.

TOWER DESIGN, CONSTRUCTION, INSTALLATION, AND OPERATION

The diversity, quantity, and quality of oceanographic data obtained from the NEL Oceanographic Research Tower demonstrate its ability to meet the requirements of shallow marine investigation. This ability has not occurred by chance. Behind the tower's overall design and its multifaceted facilities lie thousands of hours of planning by NEL scientists and engineers. And this planning continues. The tower's work area has been doubled in the past 6 years. In addition, newly developed instrumentation and techniques are continually being tested and, if successful, incorporated into the tower's permanent capabilities.

CONCEPTION, DESIGN, AND SITE CRITERIA

The initial action to consider procurement of a tower was a memorandum by the author (Memo 2242-49-55) of 29 June 1955 which pointed out the advantages of such a facility to the Laboratory's mission. It also contained a preliminary structural drawing of the tower. At that time it was difficult to obtain and use ships for shallow-water oceanographic and acoustic work.

The proposal was carefully reviewed at the Laboratory and the Bureau of Ships. Funds were budgeted and eventually approved for final design and construction.

The contract to prepare plans and specifications for construction of the oceanographic tower was awarded on 18 April 1957 to Moffatt and Nichol, Inc., Consulting Engineers, Long Beach, California by the Bureau of Yards and Docks.

After selection of the site (approximately 0.8 mile offshore from Mission Beach) exploratory studies of the subbottom were made by the Rand Corporation. Jet probes and drilling techniques were used to produce a 63-foot vertical picture of the subbottom. From this information it was determined that the tower could be anchored to the sea floor with 63-foot-long steel pins.

The tower construction contract was let to McDonald Contractors, Inc., Los Angeles on 17 November 1958. Construction was completed 2 July 1959.

Sample Depth (Ft)	Soil Type	Type of Test *	Surcharge (Lbs/sq ft)
17	Medium to coarse sand and shells	F	700 1,200
25	Coarse sand and shells	F	1,000 1,500
41	Silty loam	DS	1,500 2,000
41.5	Silty loam with fine sand	F	1,500 2,000
58	Coarse sand and shells	M&D	

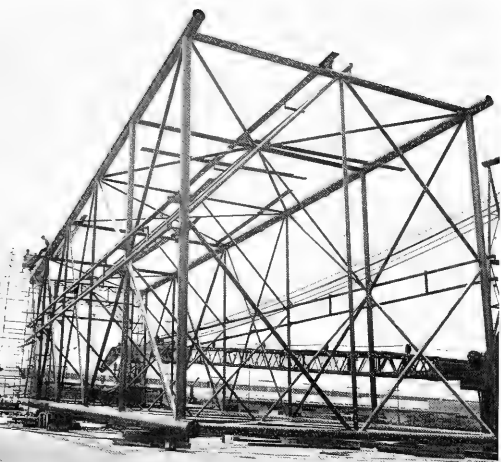
*F = Friction tests on steel; DS = Direct shear tests;
M&D = Moisture and density determinations.

THE TOWER LOCATION

1. Provides a natural open-sea environment unaffected by manmade structures.
2. Contains ocean parameters important to research problems under study by NEL scientists.
3. Presents a limited navigational hazard.
4. Possesses minimum noise from passing vessels and other man-made sources.
5. Is easily reached from NEL.
6. Provides convenient access to a shorebased power supply.
7. Provides a broad sweep of smooth sea floor, devoid of rocks, canyons, or other irregularities.

LABORATORY TESTS ON SEDIMENT CORE SAMPLES FROM TOWER SITE

Ultimate Shearing Strength (Lbs/sq ft)	Friction On Steel (Lbs/sq ft)	Moisture Content (Percent)	Dry Density (Lbs/cu ft)
	290 550	19.1 19.1	111 111
	315 590	19.4 19.4	111 111
1,140 1,465		38.8 38.8	83 83
	515 710	32.4 32.4	88 88
		22.3	108



For maximum strength, 8-inch diagonal pipe reinforcing was welded to the 16-inch diameter cylindrical legs during tower fabrication in Wilmington, California. Railway tracks were welded to three sides, and a beam was welded across the bottom for anchoring guide cables. The central part was left free of crossbeams in order to allow instruments to be lowered through the center of the structure. The open pipe at the bottom of the legs will hold steel anchoring pins. On completion, the structure was treated with preservative paint.

The partially assembled tower was floated to San Diego and lowered into place by giant crane. Orientation of the sides was made exactly N-S and E-W. The center point rests at $32^{\circ} 46' 21.1''$ 330 N, $117^{\circ} 16' 03.1''$ 939 W. Thirteen by fifteen-foot instrument house sits on barge (left).





Long 12.75-inch diameter steel pipe pins inserted into the four corner legs were driven 63 feet into the sea floor at an angle of 5 degrees from the vertical. The tops of the pins were then welded to the legs, thus securely anchoring the framework to the sea floor.

The instrument house with its cement deck was lowered onto anchor pins and framework. I-beam house supports were welded to top of anchor pins. Supports for the catwalk were also welded into place. Finally, ladders, catwalks, and the instruments were added. After 2 years' operation, this original instrument house proved too small, and was enlarged by cantilevering to the north and south.



WELDER MAKES
FINAL ATTACHMENT

FACILITIES

Lower Catwalk (Level 1)

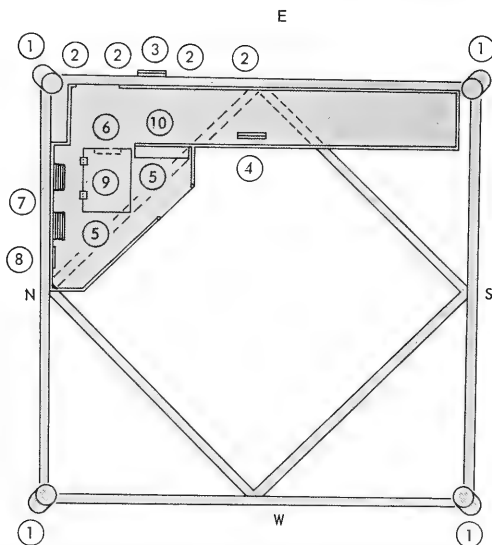
LEVEL

4

3

2

1



BOARDING AND DIVING DECK

1. Tower legs
2. Protective pilings (dolphins)
3. Boarding ladder
4. Ladder to upper catwalk
5. Diving platform
6. Diving ladder
7. Diver's compressed air hose (hookah)
8. Compressed air supply valves
9. Grating door for divers access to sea
10. Storage tray for divers tools and equipment



Long landing, loading, and working platform near the water surface extends along the east side. Surface collections and measurements are made from this steel grating catwalk.

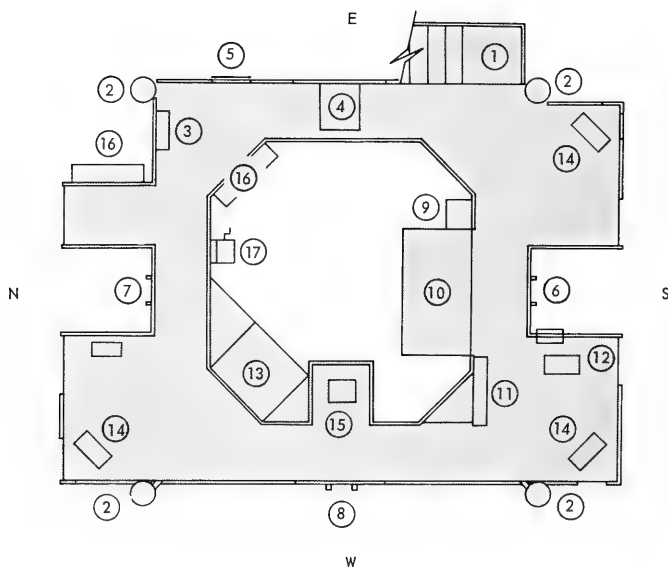


Diver descends from the diving platform to install sea-floor instrumentation. He is trailing hookah hose containing compressed air at 125 psi.



Scuba-equipped technician emerges from the water by climbing a retractable ladder which extends down through a trap door in the center of the diving platform.

Upper Catwalk (Level 2)



WINCH, FILTERING, AND LIVE SPECIMEN DECK

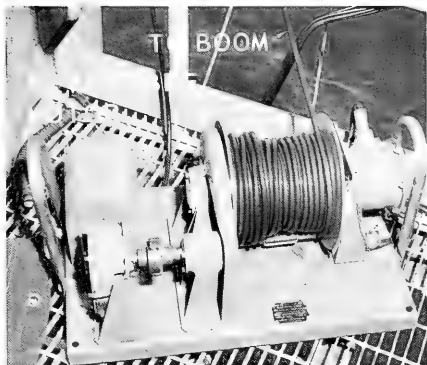
- | | |
|-------------------------------|---------------------------------------|
| 1. Ladder to main deck | 11. Aquarium |
| 2. Tower legs | 12. Winch and controls for south cart |
| 3. Electrical junction box | 13. Analysis and recording cabinet |
| 4. Trapdoor to lower catwalk | 14. Isotherm follower winches |
| 5. Boarding ladder | 15. Winch for west track |
| 6. South vertical rail tracks | 16. Working platform |
| 7. North vertical rail tracks | 17. Equipment lowering reel |
| 8. West vertical rail tracks | |
| 9. Radio and intercom box | |
| 10. Storage cabinets | |



Technician operates winch controlling west rail cart while paying out signal and power cable. Exchangeable cables and hoses are attached to the hand rail on this deck.

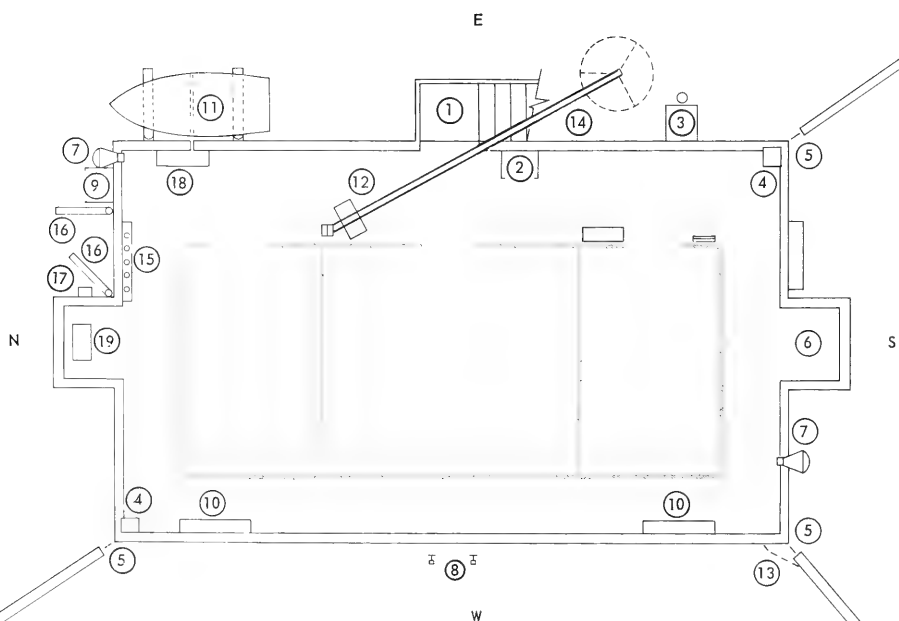


Freshly caught biological specimens are kept alive in this 44-gallon stainless steel and glass aquarium.



Portable winch automatically winds and unwinds cable in order to follow the changing depth of an isothermal layer. One winch is mounted on each of three corners of this deck. The cable extends from the winch to the ends of long booms and supports isotherm follower sensors.

Main Deck (Level 3) EXTERIOR



WATER SAMPLING AND GENERAL OPERATIONS

- | | |
|--------------------------------|-----------------------------------------|
| 1. Ladder | 11. Work boat/lifeboat |
| 2. Work bench | 12. Base and controls for cargo hoist |
| 3. Incinerator | 13. Foghorn |
| 4. Beacon lights | 14. Cargo boom |
| 5. Isotherm follower booms | 15. Water bottles and rack |
| 6. Work platform | 16. Davits |
| 7. Floodlights | 17. Electric winch for bathythermograph |
| 8. West vertical rail tracks | 18. Work platform |
| 9. Bathythermograph platform | 19. Water bottle winch |
| 10. Thermometer and BT storage | |



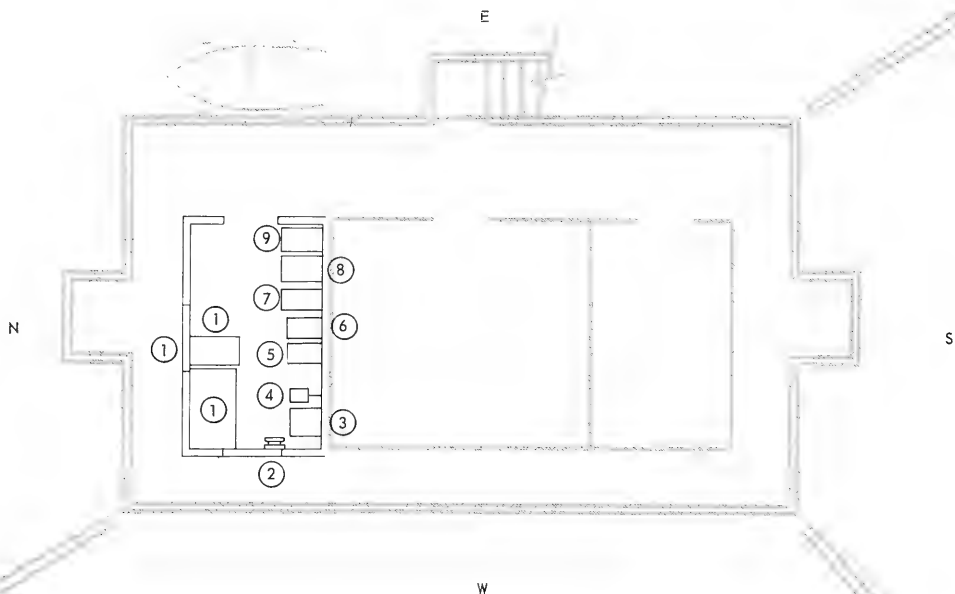
Bathythermograph lowered by an electric winch (left) provides detailed information on water column temperatures. Surface thermometer bucket (hanging from davit), Nansen bottles on rack, and floodlight are at right.



Supplies and equipment are transferred from boat to tower by means of a 700-pound capacity nylon basket attached to this 18-foot loading boom. Combination workboat and lifeboat stands ready for use (left, foreground). It is lowered with the same boom.

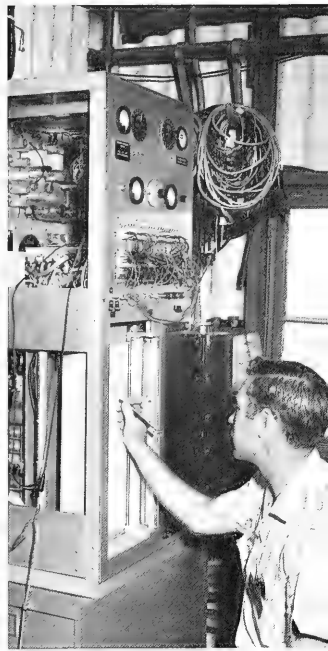
The isotherm follower booms, foghorn and searchlights are attached at this level. The west railway track terminates here for the installation of cart and equipment.

NORTH ROOM



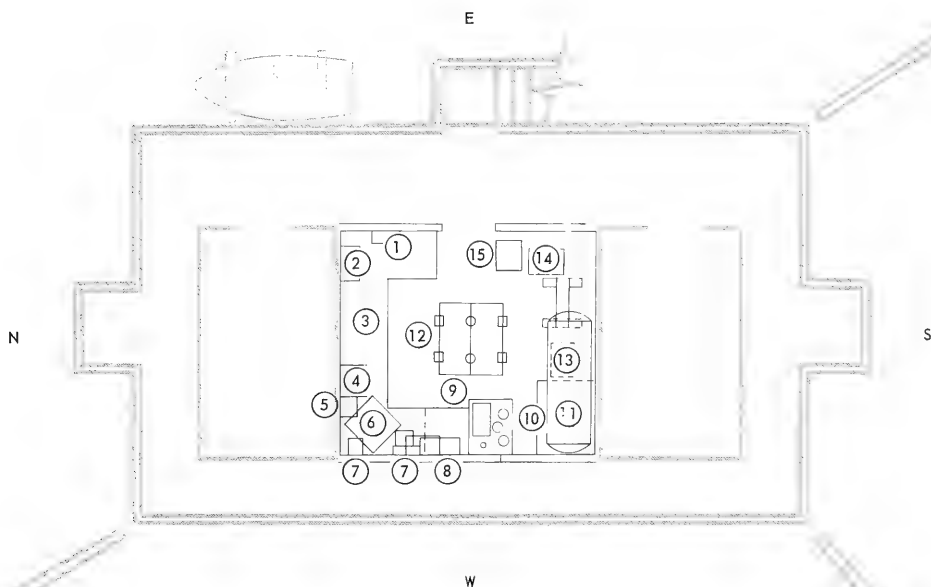
ELECTRONICS AND RECORDING

1. Work area and removable recorders
2. Gas-filled cables from circular array
3. Analog recorder for vertical and horizontal temperature array
4. Underwater communication system
5. Punch-tape recorders for vertical and horizontal temperature sensors
6. Alternate punch-tape recorder for vertical and horizontal temperature sensors
7. Temperature recorder and WWV time check receiver
8. Digital-data temperature recording system for thermally lagged temperature sensors
9. North cart depth and temperature meters, hydrophotometer, and swell recorders



(Left) Recorders and other electronic equipments are mounted side-by-side in 19-inch racks along the south wall. (Center) The punch-tape recorders are used interchangeably and concurrently. They can be connected to a choice of several sensing instrument cables in the recording room. (Right) Fifty-two sensors transmit vertical and horizontal temperature readings to this analog recorder which is also connected to the adjacent punch-tape recorder.

(Level 3) CENTRAL ROOM

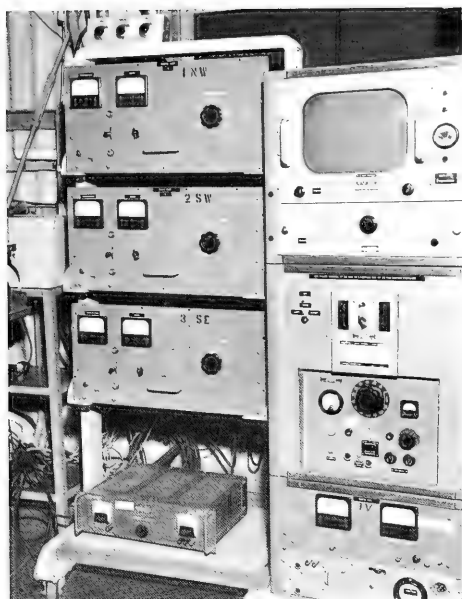


CENTRAL OPERATIONS AND LIVING ROOM

- | | |
|-------------------------------------------|---------------------------------------------------------------|
| 1. Tower-ship-shore communications system | 8. Anemometer meter and recorder |
| 2. Power switches and circuit breakers | 9. Galley (oven, sink, range) |
| 3. Equipment repair and assembly area | 10. Head |
| 4. Sonar system | 11. Fresh water storage tank (140-gallon capacity) |
| 5. Compressed air hose | 12. Instrument trapdoor |
| 6. Vertical temperature analog recorder | 13. Underwater TV and movie camera system |
| 7. Cathodic system monitor and control | 14. Electronics and controls for automated isotherm followers |
| | 15. Current meter recorder |

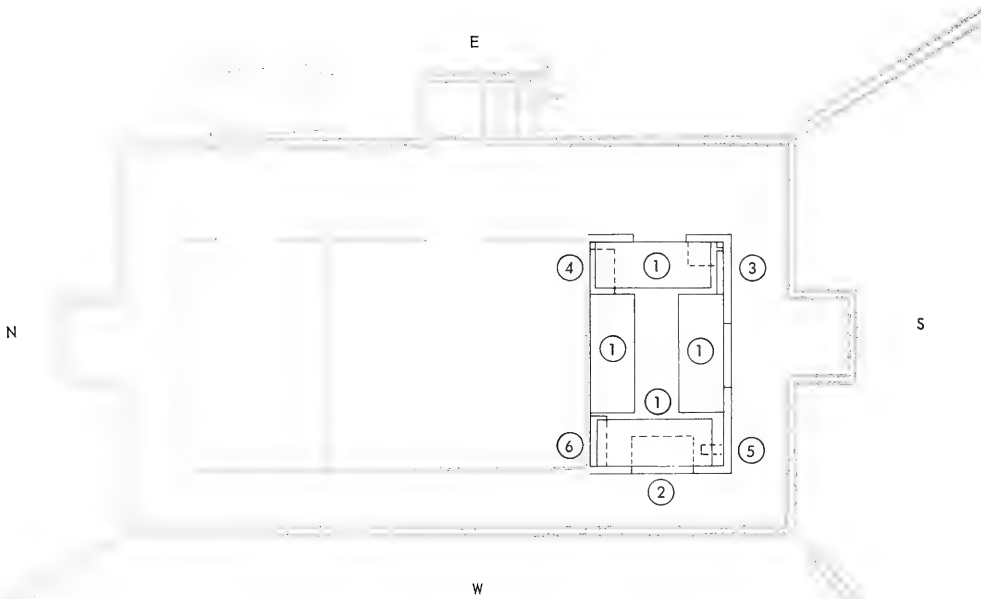


Central operations room is used for a variety of purposes, including equipment repair. A small supply of spare parts is available. Ship-shore communications and electrical supply are controlled in one part of this room. An intercom connecting all rooms and three levels is also available.



Recording and monitoring take place along the north (left) and south (right) sides of the central room.

Level 3 SOUTH ROOM



BUNK ROOM, OFFICE, AND WET LABORATORY

1. Bunks
2. Desk
3. Fresh water (wash basin)
4. Tool storage area
5. Welding generator
6. Office and optical supplies



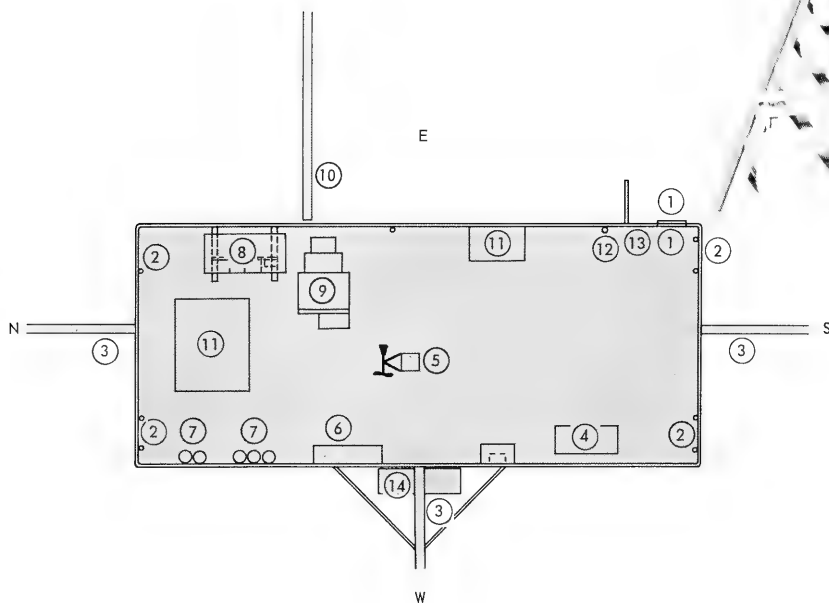
Six Navy-type bunks are available in the south room. The lower bunks may be tilted up, removed, or converted to laboratory benches. A deck with storage shelves is near the west window. An electric welding generator is mounted in one corner. Foul-weather gear is available. This room also serves as a changing area for divers.



By placing precut plywood over the lower bunks they may be converted to laboratory benches. These are especially needed for wet lab, chemistry, and biological work.

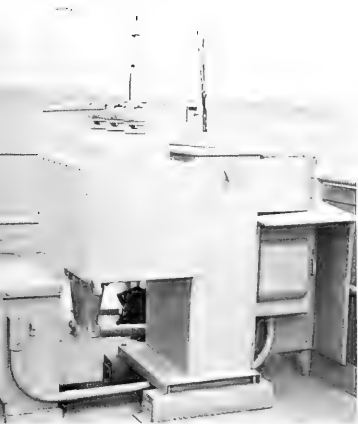
Upper Deck (Level 4)

Time-lapse camera and convex mirror, used in horizontal current and sea-surface slick studies, are mounted atop the 40-foot mast.

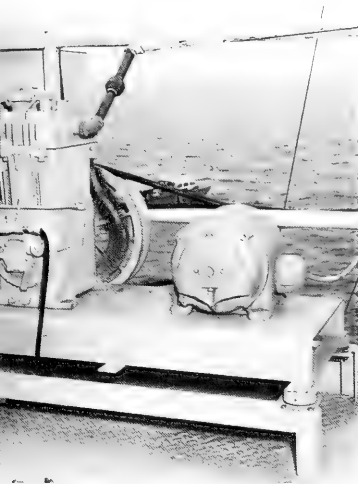


UPPER DECK INSTRUMENT PLATFORM

- | | |
|---------------------------------------------------------------|-----------------------------------|
| 1. Ladder | 8. Power junction box |
| 2. Deck lights | 9. Transformer |
| 3. I-beam booms | 10. Loading boom |
| 4. Air compressor | 11. Storage areas |
| 5. Mast, mirror, and anemometer | 12. Intake for fresh water supply |
| 6. Auxiliary power supply (for foghorn and navigation lights) | 13. Hoist |
| 7. Nitrogen tanks | 14. Air storage tank |



Power for instruments, heating, and lighting is provided by San Diego public utility facilities. This large transformer converts the 4160-volt line power, sent over submarine cable, to 440, 220 and 110 volts. Total transformer capacity is 30 kilowatts. A 110-volt supply is also available.



Air compressor and compressed air tank provide air for hookah, bubble screen, and other uses. One hundred cubic feet is available at 125 psi, at the rate of 20 cu. ft./min.



The instrument house roof also serves as a platform for sea-surface observations. Direction and speed of current can be determined by tracking the floats of suspended drogues with a transit mounted at a known fixed position.

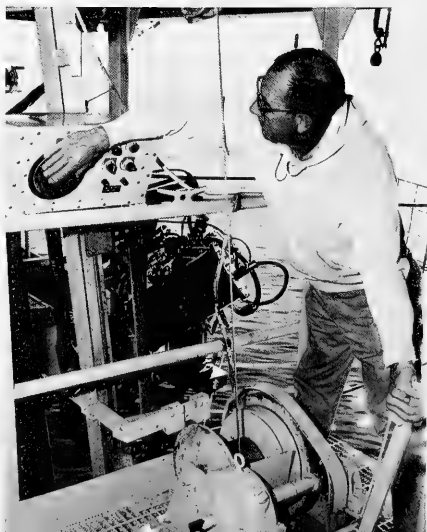
Equipment Railways and Underwater TV

The vertical railway system has played a vital part in many tower investigations. Carts with their diversified array of sensing devices are raised and lowered over its steel tracks, which are spaced 30 inches apart. The instruments (discussed previously in Part II) transmit data by cable to the instrument house.

The underwater television system mounted on the vertical railway tracks has proved its usefulness in many studies. The system is composed of an underwater television camera and a 16-mm motion-picture camera in watertight housings, depth and temperature sensors, and six 500-watt floodlights.

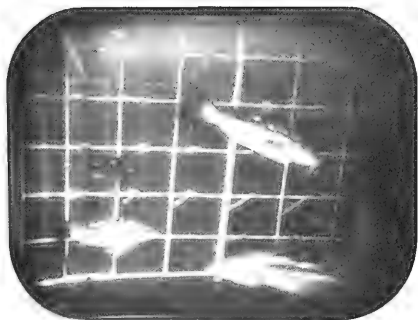
Control of the unit is through a coaxial cable connected to the monitoring system in the instrument house where the cameras and lights can be tilted and trained. Focus and iris adjustments are also controlled from the monitor console. The underwater motion-picture camera can be turned on when a desired subject is seen on the TV monitor. The system is used to study marine organisms, water motion, operation of equipment, and behavior of objects placed on the sea floor.

Operator prepares to lower underwater TV and motion-picture camera unit. The equipment on the railway tracks is raised and lowered on steel cable by an electric winch. Power winch is at lower right and control panel is at upper left.





TV system poised on the south rail track and ready for lowering. The attached 36- by 48-inch grid is divided into 6-inch squares. This is used as a reference in water-motion studies. The grid serves as a background scale in the study of fish sizes and is used to determine rate of movement.



Fish are identified on the TV monitor by their shape, markings, and behavior. Kelp bass, with light spots on the dorsal side, move rapidly through the light field.



Underwater, the white nylon yarn streamers indicate current movement. The perch in foreground is 9 inches long. Mackerel in background are tower residents during winter.

Railway tracks extend from main deck on the west side and from the second deck on the north and south sides. Carts are held firmly to the track by roller-type shoes which permit the cart to be moved freely up and down the track.

Scuba and Hookah Diving

Scuba and hookah diving equipment is used at the tower to install oceanographic instruments on the tower framework and on a broad area of the surrounding sea floor. The tower is equipped with an air-compressor system on the upper deck. Air at 100 psi is routed through high-pressure piping to the lower decks for use with hookah and pneumatic devices. Scuba tanks are filled ashore, then transported to and stored on the tower.

Maintenance and repair of underwater sensors, connectors, and moving parts are undertaken by diving technicians. Underwater maintenance of the structure also requires the services of diving personnel. This maintenance includes removal of marine fouling, installation and servicing of cathodic protection devices, and replacement of protective materials.

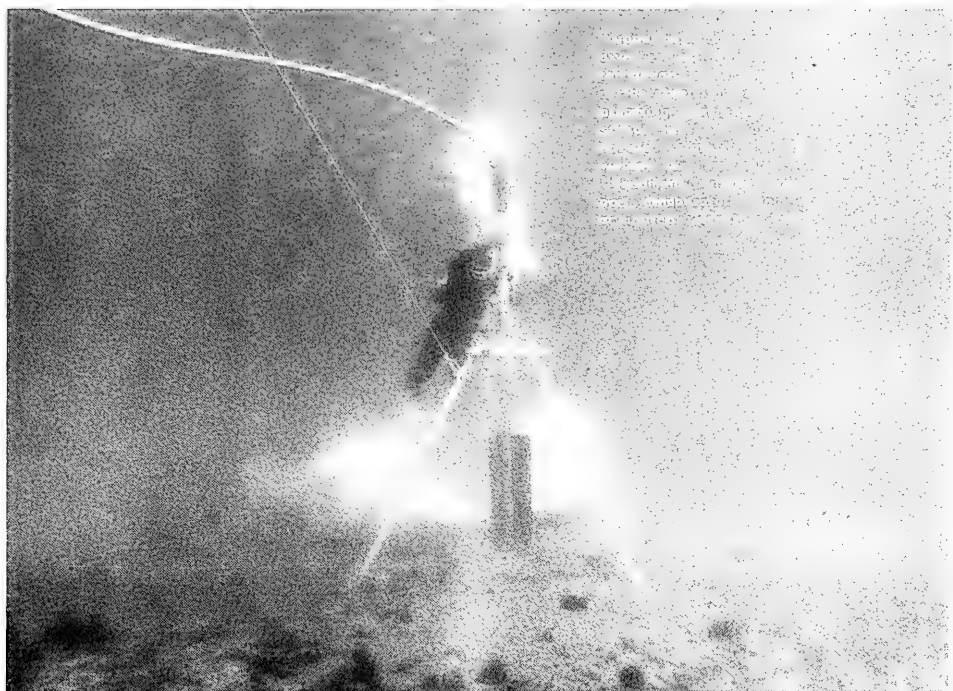
The divers have developed or modified tools and equipments to facilitate their operation. Pneumatic tools have been redesigned to work underwater and thus increase efficiency during maintenance periods. Letters patent have been issued for some of the unique devices developed for use in the area around the tower.



Pneumatic chipping hammers, operated on the same compressed air as the hookah gear, are used to clean marine organisms and other types of fouling from the underwater portions of the tower structure. Excessive fouling adversely affects the normal flow of ocean currents.



Biologists are able to study the ecology of an ever-changing community and contribute their findings to the overall knowledge of the ocean. The collection of delicate specimens such as this siphonophore may be more carefully done by divers than with nets lowered from the tower.



Underwater Communication

The tower's underwater communications system facilitates joint operations between scientists and divers. In addition it is used during test or repair of instruments associated with the tower. The underwater system used at the tower is an adaptation of commercial systems and is now called "Towercom." With the Towercom, divers can communicate with each other. Confirmation that the diver has completed his mission and that the equipment is in operation makes for efficient use of the limited time a diver may stay on the bottom.



Communication equipment worn by the diver includes a special mouthpiece with microphone, a magnetic earphone, and a short length of cable attached to an underwater plug.



The diver connects phone plug into any station located throughout the underwater portion of the tower arrays.

THERMISTOR
BEAD ON
30-FOOT PIPE

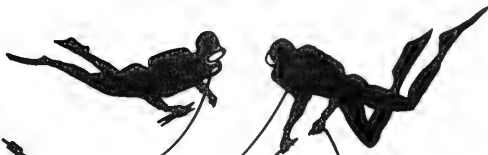
JUNCTION
BOX

SPEAKER-AMPLIFIER



The topside unit of the Towercom consists of speaker, amplifier, and associated electronics. The unit is placed near the temperature-recording system in the tower so the engineer may observe the behavior of the sensors being repaired and communicate instructions to the divers.

60 FEET TO SURFACE
↑



SEA FLOOR

When leaks develop at a thermistor station, divers descend, disconnect the faulty sensor, repair or replace it, and check for proper operation with an engineer monitoring both the temperature sensing and Towercom system. Communication is facilitated by plugging the divers' leads into the electrical system of the array. Divers can use either scuba or hookah with Towercom equipment.

CABLING

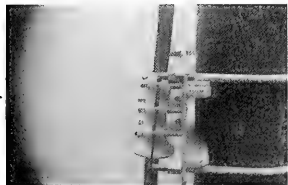
The handling of underwater cables is of primary importance to the tower program, since leakage in either power or signal cable leads to faulty or no data transmission. Special clamps and new techniques are used to prevent abrasion of these cables.

The cable is laid on the sea floor. In deep water it soon becomes partially buried by sand ripples.



Heavy double-armored cable from a Mission Beach utility line carries electrical power for the tower (background). The cable is being jetted 8 feet below the surf and beach level in this 1959 installation photograph.

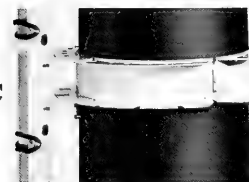
A



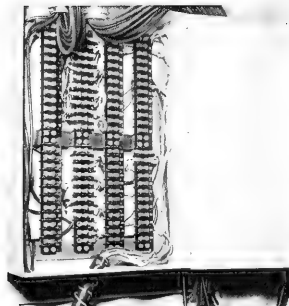
B



C



Protective bell-shaped clamp starts power cable up tower leg (A) through strong permanent clamps (B). The instruments are grounded by another cable which leads to a large copper plate buried in the sand near the tower. Signal cables require changing as sensors are installed, removed, and repaired. They are encased in old fire hose to avoid abrasion against the tower by the surging water. They are then clamped with single-channel brackets (C) held out from the tower leg. These brackets have been modified to allow additional cables of any size to be attached underwater. Rubber bands made of surgical tubing hold the cables in place.



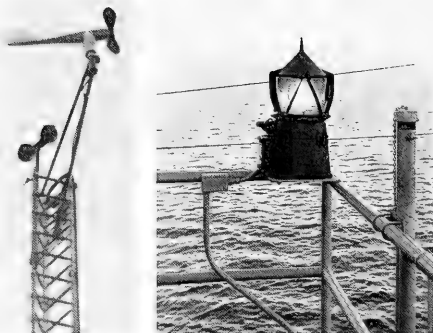
Within the instrument house signal cables are connected to 98 terminals on patch panels. This bundle of signal cables leads through conduit to recorders in the various rooms.



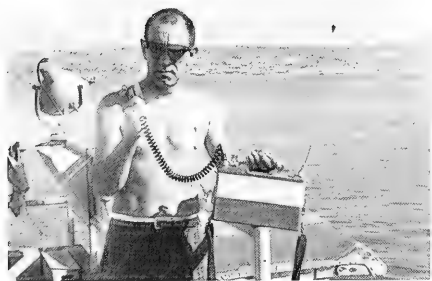
Underwater signal cables may become tangled by water motion unless they are carefully attached to a fixed support by clamps or brackets.

SAFETY

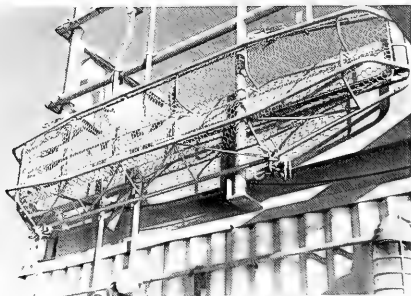
The safety of personnel working on and around the tower is of primary importance. All necessary safety precautions are therefore taken. The Safety Officer of the Laboratory issues safety glasses, shoes, hard hats, and first aid supplies. Other equipments such as lights and foghorn are approved and inspected by the Coast Guard. The tower has had a perfect accident-free record.



Navigation safety is maintained by remotely controlled foghorn. Lights at the masthead are for warning planes, and those on the NW and SE rails are for ships. The lights and radio are powered by the city power supply. Should a power failure occur lights are automatically shifted to a battery source.



The tower is equipped with a back-up, battery-operated walkie-talkie on the same frequency as the usual radios.

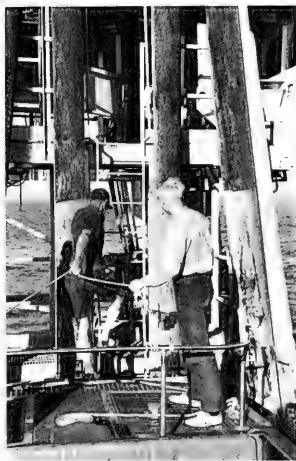


First aid supplies and a stretcher are available. Also, although nearly all the tower is of fireproof construction, extinguishers are available in strategic locations for any possible equipment or paint fire. Life rings are conveniently placed on the rails of the upper three decks. The tower also has a lightweight life and workboat provided with Mae West life jackets.

A



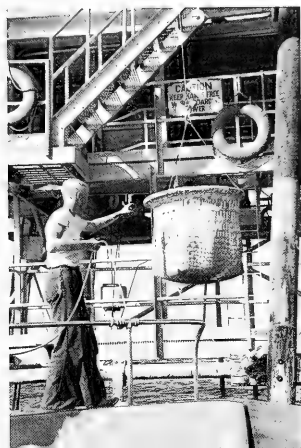
B



C



When landing personnel on the tower, the personnel boat approaches the east (or leeward) landing ladder stern first. Heavy double-level rubber air-filled fenders provide a soft landing against the wooden dolphins (A). The person disembarking stands on the unobstructed stern, holding a safety line for balance (B). As the boat eases up to the ladder, the passenger steps a distance of about one foot from the boat to the rungs of the ladder which is recessed between the dolphins (C). On rough days the transfer to the tower takes place as the crest of the wave is under the boat. When disembarking from the tower, the person steps from the ladder to the boat, with boat personnel standing by and holding the safety line for the disembarking person.



All equipment (even small articles) is brought aboard in the basket. Thus boarding personnel are unincumbered. For very large equipment, the basket is removed and a sling is attached.

PROTECTION

Sea Gull Deterrent

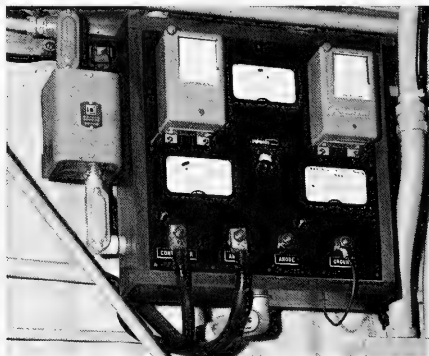
When the tower was originally installed, sea gulls lined the rails and littered the decks. To rid the installation of these pests, a covey of imitation owls was posted at strategic points around the tower. Initially, the owls were successful in scaring the birds away. Later they became accustomed to the owls and returned. Periodic broadcasts of tape-recorded gull distress calls were then introduced. The cries of anguish take place every hour. As a result the tower is now nearly free of sea gulls.



Mounted owl acts as a sea gull deterrent. Another deterrent is 3-minute herring gull distress calls broadcast from speakers mounted on upper deck rail.

Fouling and Metal Protection

Corrosion protection below the water level was originally provided by a cathodic system consisting of four batteries of zinc anodes charged with low voltage. The voltage balances the electrical potential created by the steel framework in salt water. After 5 years, the underwater portion of the tower shows no appreciable damage due to corrosion. A more permanent system consisting of platinum anodes has now been installed to replace the zinc.



Meters and controls for cathodic protection are mounted in the instrument house.

A



B



Fouling of the tower's underwater structure by barnacles, mussels, and other sessile marine organisms is controlled by an annual scraping. The work is done by hookah (A) and scuba (B) equipped divers using scraping irons and hydraulic hammers. The scraped-off animals and their shells are removed from the area so as to keep the sea floor in a natural state. In fact nothing is thrown over the side that may litter the bottom.

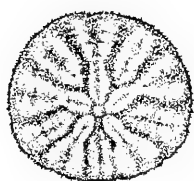
Metal protection overlapping the tidal and splash zone (-2.5 to 14.5 feet) is provided by a 3/16-inch neoprene coating. Other metal areas are painted periodically with epoxy paint.



PART IV.

FUTURE PLANS AND SUMMARY

This part summarizes the report and points out the need for a new tower in deeper water. Recommendations for new research are also made.

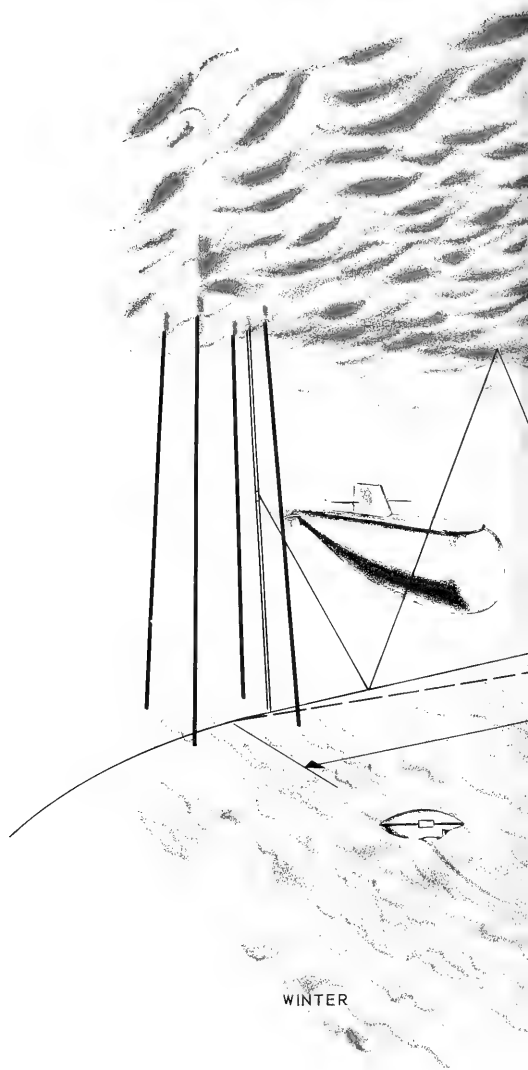


THE NEED FOR DEEPER RESEARCH

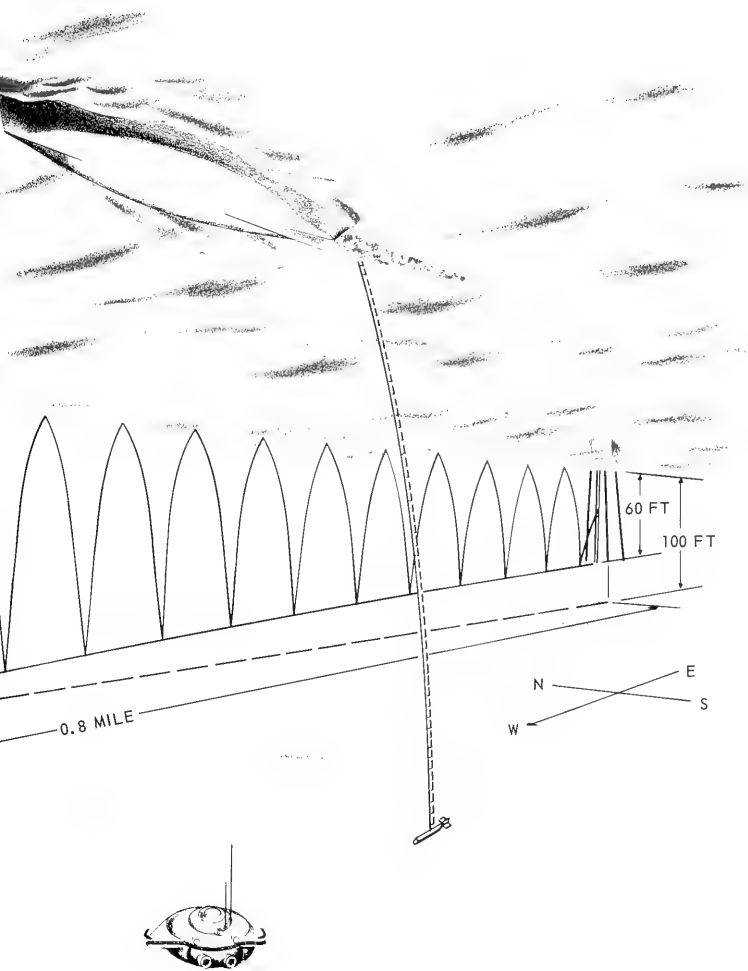
As studies of the inshore marine environment progress, it becomes necessary to extend oceanographic research into the next deeper stage -- the 100-foot level. An oceanographic tower located west of the present tower is required to supply essential data on this deeper region.

Utilizing the techniques developed and the instrumentation employed in present tower studies, a tower at the 100-foot depth would:

1. Permit extensive studies of the relationship between the marine environment and the operation of ships, submarines, and deep-submersible vehicles. These studies are not practical with the present tower.
2. Enable studies of motion, acoustics, chemistry, biology, and geology to be continued in the new deeper water area.
3. Make possible the study of thermocline characteristics for a season up to 50 percent longer than is possible at the present location.
4. Create a stable, fixed-path range for sound and radar transmission experiments between the present and new tower.
5. Allow study of the modification in characteristics of surface and internal waves as they progress shoreward.
6. Efficiently support the complex requirements of a sea-bottom laboratory and provide an ideal base for development of man-in-sea type studies.



Proposed acoustic range between towers would be used in the study of short-term and seasonal variations in sound transmission. Surface craft and subsersibles could participate in research and operational studies in conjunction with the deeper-water tower.



SUMMER

SUMMARY

1. The Navy Electronics Laboratory (NEL) has constructed a unique oceanographic research tower for the study of a broad range of marine environmental problems.
2. The tower is readily accessible from NEL. It provides laboratory-like conditions (stability, quietness, extensive instrumentation) for shallow-water research in the open sea. It is adapted to a wide diversity of studies. It is also more economical to operate than a ship anchored in the same location.
3. The tower is being successfully used to study water motion, underwater acoustics, electromagnetic propagation, marine chemistry, marine biology, and marine geology. It also serves to test and evaluate newly developed techniques and equipment and to furnish assistance to other Navy laboratories working on oceanographic problems.

RECOMMENDATIONS

1. Expand facilities on the NEL Oceanographic Research Tower to meet the need for a larger work area.
2. Initiate new research, including investigations with radar, infrared, and laser, and at the air sea interface.
3. Build a new similar tower west of the present one, in water 100 feet deep. This deeper tower will:
 - (a) Permit study of water-structure features at greater depth and allow for investigating the seasonal thermocline for longer periods of time.
 - (b) Facilitate joint research projects with ships, submarines, and other submersible vehicles requiring deep water.
 - (c) Serve as a second platform for intertower acoustic studies.

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